

Physiology

Of The

Eye



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1)- The Lens :-

Functions of the crystalline lens :-

- Transparency.
- Accommodation.
- Refraction (+17D inside the eye).
- Absorption of UVR.

I)- Transparency :-

Transparency of the crystalline lens is due to :-

a)- Anatomical factors :-

- lens is avascular & has no nerve supply.
- lens capsule protect lens substance from the surrounding fluid.
- lens epithelium → single layer that line the capsule upto the equator.
 - RI of epith = RI of capsule = RI of aqueous.
 - no scattering nor reflection of light.
 - if damaged → change permeability → opacity.
- Lens fibres are regularly arranged, densely packed together & organized → ↓ reflection & ↓ scattering of light → most rays enter inside the eye.

b)- Physiological factors :-

- metabolic activities of the epith help to pump out excess water & Na^+ which enter the lens from the surrounding fluid.

c)- Physiochemical factors :-

- All lens constituents have almost the same RI.
- Constant water content.
- Ptns of lens fibers are non-opalescent.

II)- Accommodation :-

Def. :- is a process of changing the dioptric power of the lens & so image of any object located between far & near points will be focused on the retina.

Mechanism :-

a)- Modified Helmholtz theory :-

- the lens is capable of changing its shape due to :-
 - elasticity of the capsule.
 - plasticity of the lens substance.
- At the equator, the capsule is maintained in lateral tension by the suspensory ligament (zonules) & thus the convexity of the lens is least (eye at rest or un-accomodated).
- Contraction of the circular part of the ciliary muscle will lead to relaxation of the zonules by ↓ the circumlental space → ↓ lateral tension on the capsule → lens bulge towards least resistance (ant. → aqueous & pupil - post. → vitreous) → so lens bulge anteriorly → ↑ ant. Curvature → ↑ power of the lens.
- Dioptric power of the eye is +14D in young age, ↓ with age till +1D at 60 years old due to ↓ capsule elasticity & ↓ plasticity of lens substance with age.
- This theory is proved by changes in the eye that occur during accommodation.

b)- Tshering increased tension theory :-

- Contraction of the ciliary ms → compression of lens against anterior vitreous face → bulging of ant. surface.
- Anatomical observation during accommodation don't support this theory.

c)- Dual nerve control theory :-

- There is mutually antagonistic activity.
- Parasympathetic innervation → cont. of circular fibres of the ciliary ms → clear near vision (3rd nerve).

- Sympathetic innervation → cont. of radial fibers of ciliary ms (antagonize circular fibers) → clear far vision.

Changes occurring during Accomodation :-

- Contraction of Radial fibers of the ciliary ms → CB & choroid are pulled forwards.
- Contraction of Circular fibers of the ciliary ms → relax suspensory lig. (evidenced by direct visualization of the zonules through iris coloboma).
- Lens changes → lens sink down & become tremulous (↓ tension by the Zonules).
 - capsule become loose & Purkinje image become smaller (due to ↑ curvature of the ant. capsule).
 - Ant. pole move forward, Post. Pole is fixed & ↑ lens thickness.
 - ↓ lens diameter & ↑ diopetric power.
 - ↑ RI of the lens due to displacing of lens fibers towards the center.
- AC become shallower.

Stimulus for Accomodation :-

- Blurring or spherical aberration.
- Chromatic aberration.
- Nearing of object (awareness of proximity).

Center of Accomodation :-

- Occipital cortex in involuntary accomodation.
 - Frontal cortex in voluntary accomodation.
- Latent period is 0.5 sec. on change from near to far (time is ↑ by age).

Near Reflex :-

- Miosis - Convergence - Accomodation.

Far & Near points of Accommodation :-

- Far point (PR) :- farthest point of clear vision with relaxed accommodation.
- Near point (PP) :- nearest point of clear vision at which the accommodation is fully exerted.

Types of Accommodation :-

a)- Physical :-

- depends on lens elasticity & compensability.
- measured by Diopter.
- ↓ in old age due to lens sclerosis.
- Ciliary ms is normal.
- failure occur between 40 - 50 years old (i.e. presbyopia).

b)- Physiological :-

- depends on ciliary ms contraction.
- measured by Myodioter.
- ↓ in debility → eye strain.
- lens is normal.
- failure occur at any age.

N.B. Myodioter :- contractile power of the ciliary ms required to ↑ the refractive power of the eye by +1D.

Amplitude of Accommodation :-

Def :- difference between dioptric power of the eye at near & far points (fully accommodated eye & at rest).

Amplitude of accommodation ↓ in night → night presbyopia (lens is flattened).

Measurement :-

a)- Objective :-

- by Purkinje image on ant. lens surface (accommodation $\propto 1/\text{size}$).
- by Refractometer (accurate) or Optometer.
- Dynamic Retinoscopy at a far object then at a small near object (target) on the retinoscope then get the difference.

b)- Subjective :-

- determine the near point (PP) distance & the far point (PR) distance
Then amplitude of accommodation = $100/PP - 100/PR = \text{Diopters}$.

Factors affecting amplitude of accommodation :-

a)- Refractive state :-

- myopia $\rightarrow \downarrow$ accommodation.
- hypermetropia $\rightarrow \uparrow$ accommodation.

b)- Age :-

- childhood $\rightarrow PP\ 7\text{cm} \rightarrow +14D$.
- 40 years $\rightarrow PP\ 25\text{cm} \rightarrow +4D$.
- 60 years $\rightarrow PP\ 100\text{cm} \rightarrow +1D$.

c)- Adaptation :-

- at night $\rightarrow \downarrow$ accommodation.
- at light $\rightarrow \uparrow$ accommodation.

d)- General condition :-

- debility $\rightarrow \downarrow$ accommodation.

e)- Local disease :-

- glaucoma.
- asthenopia :- failure of muscular effort spent in accommodation as in General debility.
- Presbyopia :- due to lens sclerosis (hardness). Average age is 45 years (add the weakest +lens that gives comfortable clear vision at the usual near work distance.
- Paralysis of accommodation.
- Spasm of accommodation may occur in children with mild degree of astigmatism.

Convergence :-

* Def. :- a process during which both visual axes are directed inwards toward a near object.

* Types :-

a)- Tonic :-

- is the basic tonus of the medial recti with eyes in the 1ry position &

free from any fusional impulses.

- Present since birth.
- $\uparrow$ in children & $\downarrow$ with age.

b)- Proximal :-

- produced by sense of nearing of an object.

c)- Fusional (Optokinetic) :-

- it's optomotor reflex which maintain binocular vision by projecting similar retinal images on corresponding retinal points.
- It occurs without change in refractive state of the eye initiated by bitemporal retinal image disparity.

d)- Accomodative convergence :-

- convergence which is induced by stimulation of accommodation.
- a portion of total convergence initiated on accommodation to a stimulus (blurred retinal image due to nearness of an object).
- * Hypermetropia :- excess accommodation $\rightarrow$ excess convergence $\rightarrow$ frontal cortex inhibit linkage between accommodation & convergence.
- * Myopia :- convergence is exercised in case of excess accommodation in order to maintain binocular single vision.

• Far point of convergence :-

- Farthest point when eyes are completely at rest with slight divergence.
- Visual axes meet behind the eye.
- Far point is behind ∞ .

• Near point of convergence :-

- Nearest point to which eyes can converge without diplopia.
- Near point is normally 7 - 8cm infront of the eye.
- Visual axes meet infront of the eye.

• Range of convergence :-

- Distance between far & near points of convergence.

• Amplitude of convergence :-

- Difference in diopetric convergence power of eyes at near & far points of convergence (normal amplitude 10.5 m.a. $\rightarrow$ 9.5 +ve & 1 -ve).

- It may be :-
 - a)- positive :- part of convergence between near point & ∞ .
 - b)- negative :- part of convergence beyond ∞ (behind eyes).
- Measurement of amplitude of convergence :-
 - a)- *Meter angle* :-
 - def. :- angle through which eyes have to rotate from 1ry position to fixate an object 1 meter away in middle line.
 - patient look at ∞ then look at 1 meter from baseline (between the two centers of rotation).
 - the eye will converge by 1 m.a. = 1/distance & the same when if patient look at 2 meters = 0.5 m.a. & at 0.33 meters = 3 m.a.
 - b)- *Prism diopters* :-
 - +ve convergence measured by strongest prism base-out that allow vision without diplopia (one prism in front of one eye).
 - -ve convergence measured by strongest prism base-in that allow vision without diplopia.

Amplitude = +ve conv. - -ve conv.

Convergence of each eye in Δ = convergence in m.a. $\times$ 1/2 IPD in cm.

Accommodative - Convergence / Accommodation (AC/A):-

- *Def.*:- ratio between amount of convergence (prism diopters Δ) & Dioptric change in accommodation (diopter).
- *Normal value* :-
 - 3.5 - 4 Δ .
 - 4:1 i.e. +1D of accommodation is accompanied by 4 Δ of accommodative convergence & +1D of accommodation is accompanied by 1 m.a. of convergence.
 - 1 m.a. = 2° = 4 Δ of accommodative convergence.
- *Clinical importance* :-
 - Abnormal AC/A ratio is a very important cause of strabismus.

- If $\uparrow AC/A \rightarrow$ excessive convergence $\rightarrow$ esotropia on accommodation to near object.
- If $\downarrow AC/A \rightarrow$ weak convergence $\rightarrow$ exotropia on accommodation to a near object.
- Abnormal AC/A may lead to stress on patient's fusion mechanism (asthenopia & strabismus).

N.B. AC/A ratio is constant for each person & it's independant on patient's refractive state.

- *Measurement :-*

- a)- Heterophoria method :-*

- by measuring heterophoria at 6 meters then at 0.33 meters

$$AC/A = IPD \text{ (in cm)} + [(\Delta_a - \Delta_D) / D]$$

$\Delta_a \rightarrow$ near deviation in ΔD (0.33 meters).

$\Delta_D \rightarrow$ far deviation in ΔD (6 meters).

$D \rightarrow$ diopters of accommodation exerted at 0.33 meters.

Sign convention :- Eso (+) esodeviation - Exo (-) exodeviation.

- b)- Gardient method :-*

- by measuring heterophoria at 6 meters then measure induced phoria after placing -1D trial lens infront of both eyes $\rightarrow AC/A$ is the difference between the two measures.
 - by measuring heterophoria at 0.33 meters & induced phoria by putting +3D trial lens (before & after interposing +3D sphere) $\rightarrow AC/A$ is the difference between the two measures / 3.

- *Factors affecting AC/A :-*

- $\uparrow$ age $\rightarrow \downarrow AC/A$.
- Drugs $\rightarrow$ atropine $\uparrow$ & pilocarpine $\downarrow$.
 $\rightarrow$ Alcohol $\uparrow$ tonic convergence.

N.B. :- have little change with spectacles & glasses.

Metabolism of Crystalline Lens :-

I)- Carbohydrates :-

- Glucose coming from aqueous is the main substrate.
- Glucose enter the lens through lens capsule by facilitated diffusion.
- Glucose is phosphorylated into G6P inside the cells (lens fibers).
- Glucose metabolism :-

a)- Anaerobic glycolysis (80%):-

- $\text{Glucose} \rightarrow \text{G6P} \rightarrow 2 \text{ lactic acid} + 2 \text{ ATP}.$
- Hydrolysis of $\text{ATP} \rightarrow \text{ADP} + \text{P} + \text{Energy}.$

b)- Aerobic oxidation - Kreb's cycle (5%):-

- not important as lens fibers have no mitochondria.
- it occurs only in lens subcapsular epithelium (contain mitochondria).
- $\text{Pyruvic acid} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + 38\text{ATP}$

c)- Pentose shunt (10%):-

- $\text{G6P} \rightarrow \text{NADPH}_2 + \text{CO}_2.$
- NADPH_2 is energy carrier & used in sorbitol pathway.

d)- Sorbitol pathway (<5%):-

- form < 5% of glucose metabolism under normal conditions.
- $\text{Glucose} \rightarrow \text{Sorbitol} + \text{NADP}.$
- $\text{Sorbitol} \rightarrow \text{Fructose} + \text{NADH}^+$ (energy carrier).
- Energy is used in :-
 - 1)- synthesis of DNA, RNA & lens fibers.
 - 2)- active transport :-
 - * *cation transport (pump leak system):-*
 - ant. surface $\rightarrow$ active transport.
 - post. surface $\rightarrow$ passive diffusion.
 - * *amino acids transport :-*
 - actively transported at ant. surface to inside the lens.
 - passive diffusion at post. surface where it leaves the lens.

II)- Proteins :-

- Amino acids are actively transported inside lens at ant. surface & they are the substrates for ptn metabolism.
- Ptns form 33% of lens wt (> any other tissue in the body).
- Ptns are non-opalescent.
- Types :-
- ***Crystallins :-***
 - 85% of total lens ptns.
 - Present mainly in cortex & has enzymatic activity (protease & peptidase) → break lens ptns into amino acids.
 - α- crystallins (15%) → high MW & high electrophoric mobility.
 - ppt at PH < 7.
 - as age ↑ → converted into albuminoid.
 - β- crystallins (55%) → intermediate MW & electrophoric mobility.
 - ppt at PH = 7.
 - γ- crystallins (15%) → low MW & electrophoric activity.
 - ppt at PH < 7.
- ***Albuminoid :-***
 - 15% of total lens ptns.
 - Non-soluble & present mainly in the nucleus.
 - ↑ with age & cataract but it's not the cause of cataract.
- ***Other proteins :-***
 - Glycoprotein present in cell membrane of lens fibers.
 - Collagen present in lens capsule.

III)- Lipids :-

- Found in plasma membrane of lens fibers.
- Types :- sphingomyeline, cholesterole & saturated FA.
- Functions :- keep intercellular adhesions.

IV)- Other Substances :-

a)- Water :-

- lens is relatively dehydrated.
- 75% of cortex.
- 65% of nucleus.
- water content ↓ with age → presbyopia.
- water content change with blood glucose level :-
 - * Uncontrolled hyperglycemia → ↑ glucose level in aqueous → ↑ osmolarity lens dehydration → ↓ refractivity.
 - * Sudden control of hyperglycemia → ↓ glucose in aqueous → hypo-Osmolarity of aqueous → lens hydration → ↑ refractivity.

b)- Glutathione :-

- formed inside the lens → antioxidant.
 - disappear in cataract.
- Types :- reduced form (95%) & oxidised form (5%).
- Functions → antioxidant → so it's important in redox system (oxidation - reduction).
 - protect thiol group in ptns.
 - amino acids transport.

c)- Ascorbic acid :-

- present in aqueous in oxidised form then transported to the lens to be reduced & cannot return again to aqueous because reduced form cannot pass the capsule, so it's present inside the lens in reduced form (↓ in Cataract).
- Functions → lens metabolism (act as H^+ carrier).
 - formation of mucopolysaccharides.
 - antioxidant.

d)- Electrolytes :-

- Na^+ & K^+ → active transport (ant. surface) & passive diffusion (post. surface).
- Cl^- → passive diffusion.
- Ca^{++} → important for cell membrane permeability.

- Mg^{++} → important for enzymatic activity.
- PO_4 → important for metabolism.
- *Lens metabolism is essential for :-*
 - *Maintain lens transparency, water & electrolyte content.*
 - *Maintain capsule elasticity, permeability & lens temperature.*
 - *Neosynthesis of lens ptns by synthesis of amino acids from glucose metabolism e.g. glutamic acid & alanine.*
- *Lens metabolism is affected by :-*
 - *Composition of aqueous humour.*
 - *Permeability of the capsule.*

Chemical changes with cataract :-

- H_2O → ↑ in immature cataract & ↓ by maturation of cataract.
- Na^+ ↑.
- Ca^{++} ↑.
- K^+ ↓.
- O_2 consumption ↓.
- Glutathione disappear.
- Ascorbic acid ↓.
- Lens weight ↓.
- PH ↓.
- Osmolarity is changed (normally isotonic).

Changes in lens with cataract = Pathogenesis) :-

a)- Senile cataract :-

1)- Damage of Redox system :-

- aqueous contains high levels of oxidative agents e.g. hydrogen Peroxide & the lens is continuously exposed to these agents &

Resist that by 3 factors :-

- *Lens epithelium* :- use O_2 in aerobic oxidation (metabolism), so
If epithelium is altered $\rightarrow \uparrow O_2 \rightarrow$ lens fibers is altered due to toxic effect of O_2 .
- *Glutathione* :- act as antioxidant & glutathione disappear in senile cataract.
- *Ascorbic acid* :- present in reduced form & protect against toxic effect of O_2 & if ascorbic acid become oxidised $\rightarrow$ alteration of crystallins i.e. glycation of crystallins.

N.B. Glutathione prevent oxidation of ascorbic acid.

- Effect of damage of redox system (oxidation - reduction system):-
- *Protein modification* :-
 - Occurs at the level of plasma membrane of lens fibers.
 - Leads to transformation of lens fibers from soluble to non-soluble proteins e.g. 50% of methionine $\rightarrow$ sulfoxide methionine & 100% of cysteine $\rightarrow$ sulfoxide cysteine (both bound together to form disulfide bonds which is insoluble).
 - This lead to change of permeability of the plasma membrane of the lens fibers.
- *Lipid modification* :-
 - Also change plasma membrane permeability.
- *Enzymatic modification* :-
 - Alteration of $Na^+ - K^+$ ATPase $\rightarrow \uparrow Na^+$ & $\downarrow K^+$.
 - Alteration of Ca^{++} ATPase $\rightarrow \uparrow Ca^{++}$.
 - These changes lead to change in plasma membrane permeability.

2)- Role of Ca^{++} :-

- when $Ca^{++} \uparrow$ inside the lens this lead to cataract by :-
 - * inhibition of Na^+ pump $\rightarrow \uparrow Na^+$ inside the cells.
 - * activation of proteolytic enzymes.
- also $\downarrow Ca^{++} \rightarrow$ change plasma membrane permeability $\rightarrow$ cataract.

b)- Sugar cataract :-

- Occurs due to activation of sorbitol pathway when glucose is excessive inside the lens as in uncontrolled DM → ↑ sorbitol inside the lens → lens hydration.
→ glycosylation of lens fibers.
- When glucose ↑ in aqueous due to galactosemia (↓ hexokinase)
→ ↑ galactose influx to the lens → metabolised by the sorbitol pathway → formation of alcoholic form of galactose → ↑ osmotic pressure of lens → hydration.

c)- UVR & Cataract :-

- long wave lengths UVR > 310 n.m. → regeneration & formation of oxidative agents e.g. hydrogen peroxide → oxidative damage & hexokinase dysfunction → ↑ glucose inside the lens.
N.B. short wave lengths UVR < 310 n.m. has no effect because it's totally absorbed.

d)- IR rays & Cataract :-

- > 2500 n.m. → totally absorbed.
- IR rays are harmless except at high intensity.

e)- Radiations & Cataract (e.g. X-rays):-

- Radiation lead to → oxidative damage by formation of oxidative agents.
→ change plasma membrane permeability.
→ damage of DNA.
- Single large dose is more liable to produce cataract than frequent small doses.
- Shape of cataract → cortex → vacuoles & liquified fibers.
→ epithelium → swollen.
→ posterior subcapsular opacification.

f)- Microwave & Cataract :-

- Thermal effect → coagulation of lens proteins
→ oxidative damage.

- Non-thermal effect → alteration of distribution of lens proteins.
- Dose is 200 mv/cm².
- Shape of cataract the same as radiation cataract.

g)- Drugs & Cataract :-

*** *Steroids :-***

- systemic > local.
- due to alteration of plasma membrane permeability & modification of lens proteins.

• *Miotics for long time :-*

- As in TTT of chronic OAG.

• *Phenothiazines :-*

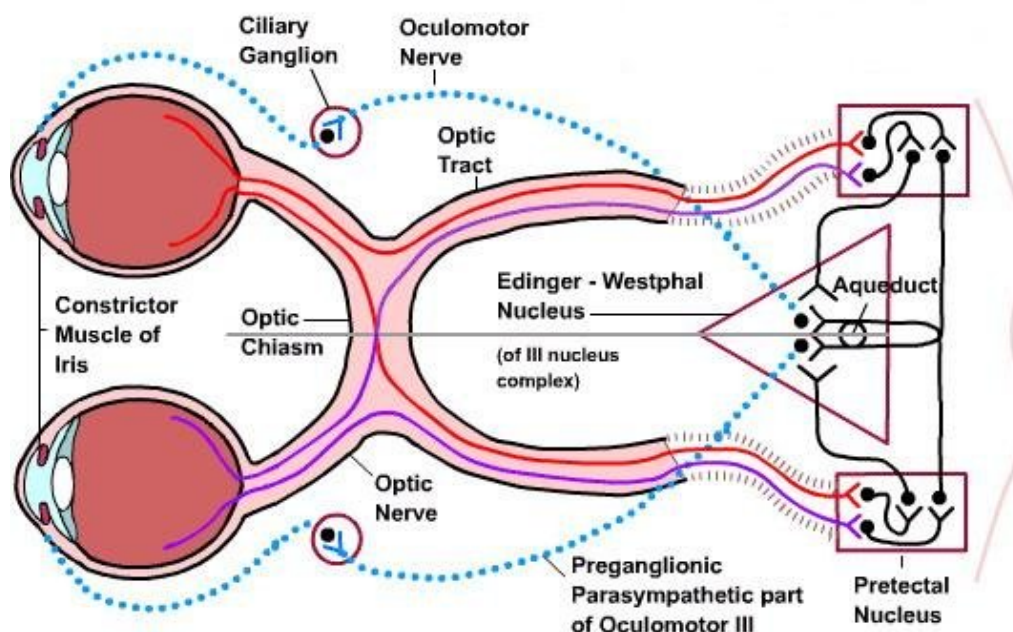
- Due to alteration of plasma membrane permeability & enhance UVR damage.

2)- The Pupil :-

Muscles of the iris :-

- *Constrictor pupillae (iris sphincter):-*
 - Circular & encircle the pupil.
 - Stronger than dilator ms.
 - Supplied by parasympathetic fibers (short ciliary ns) which arise from EWN in midbrain.
 - When contracts → dilator pupillae ms relax due to reciprocal innervation.
 - If dilator & constrictor pupillae ms are stimulated together → the constrictor is the predominant.
- *Dilator pupillae :-*
 - Radial & spread from iris radially.
 - Weaker than constrictor pupillae ms.
 - Supplied by sympathetic fibers (long ciliary ns) which arise from hypothalamus.

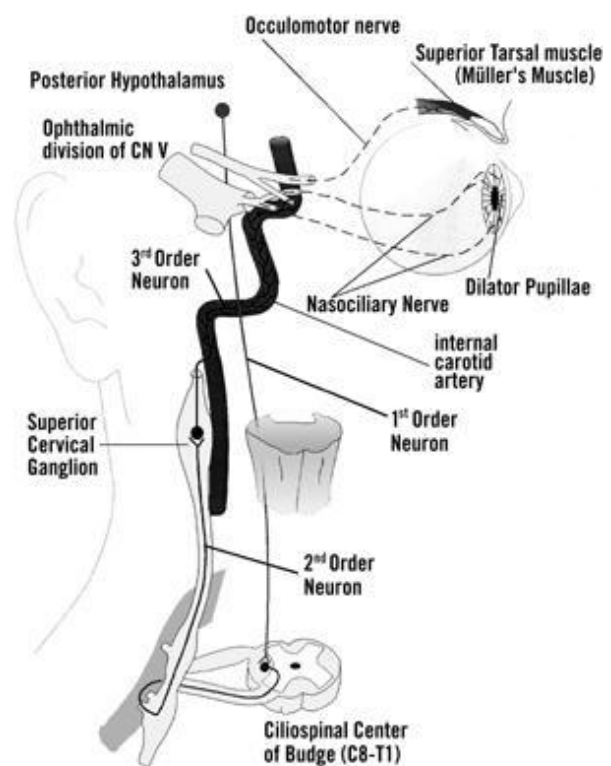
Parasympathetic pathway :-



- EWN in midbrain → Oculomotor nerve → inferior division → nerve to inferior oblique ms → ciliary ganglion → short ciliary ns → constrictor pupillae (Light reflex).
- Oculomotor nerve → nerve to medial rectus → ciliary ganglion → short ciliary ns → constrictor pupillae & ciliary ms (Near reflex).

Sympathetic pathway :-

- *Center* :- in hypothalamus → hypothalamic spinal tract with partial decussation in midbrain → so each hypothalamic center supply both cilio-spinal center of Budge mainly contralateral one (explain consensual reaction).
- *Preganglionic sympathetic* :- from cilio-spinal center of Budge of C8 - T1 - T2 (in anteromedial part of spinal segment).
- Preganglionic fibers emerge in corresponding roots (white rami communicants) then to the sympathetic chain then pass through inferior & middle cervical ganglion to end in superior cervical ganglion where relay occur.
- *Postganglionic sympathetic* :- from superior cervical ganglion enter the skull with carotid plexus to trigeminal ganglion → ophthalmic nerve → nasociliary n. → long ciliary nerves → dilator pupillae ms.



Functions of the Pupil :-

- Regulate amount of light entering the eye.

- ↓ spherical & chromatic aberrations by limiting light rays to center of the pupil.
- Constriction of the pupil → ↑ depth of focus for near objects (depth of focus is the distance between 2 objects each has different distance from the eye & both are focused on the retina without accomodation).
- Iris pigments restrict passage of light through the pupil.
- Iris-lens diaphragm act as a barrier against microorganisms.
- Iris endothelium act to phagocytose debris.
- Iris BVs has diffusional interchange with aqueous.

Normal Pupil :-

- *Diameter :-*
 - 2- 9 mm.
 - ↑ with fear, excitement, interest & pain.
 - ↓ with fatigue, sleep, at birth & old age.
- *Size & Shape :-*
 - At birth → very small because dilator pupillae is not well developed.
 - Old age → very small due to sclerosis of sphincter pupillae.
 - Sex, refraction & iris colour affect pupil size.
- *Pupil during sleep :-*
 - Small due to inhibition of sympathetic stimulation & inhibitory cortical impulses to the sphincter pupillae (parasympathetic is predominant).
- *Pupil during anaesthesia :-*
 - 1st & 2nd stages → dilatation due to fear & emotional stimulation (sympathetic).
 - 3rd stage → constriction.
 - 4th stage → paralytic dilatation.

N.B. lacrimation, eye movement & corneal reflexes are present in 1st & 2nd stages while they are absent in 4th stage.

Pupillary reflexes :-

- *Constricting pupillary reflexes :-*
 - Light reflex.
 - Near reflex.

- Orbicularis reflex.
- Trigeminal reflex.
- *Dilating pupillary reflexes :-*
 - Withdrawal of light.
 - Painful stimulation.
 - Vago-tonic pupillary reflexes.
 - Psychosensory motor reflexes.
 - Cochlear stimulation.
 - Vestibular stimulation.

I)- Constricting pupillary reflexes :-

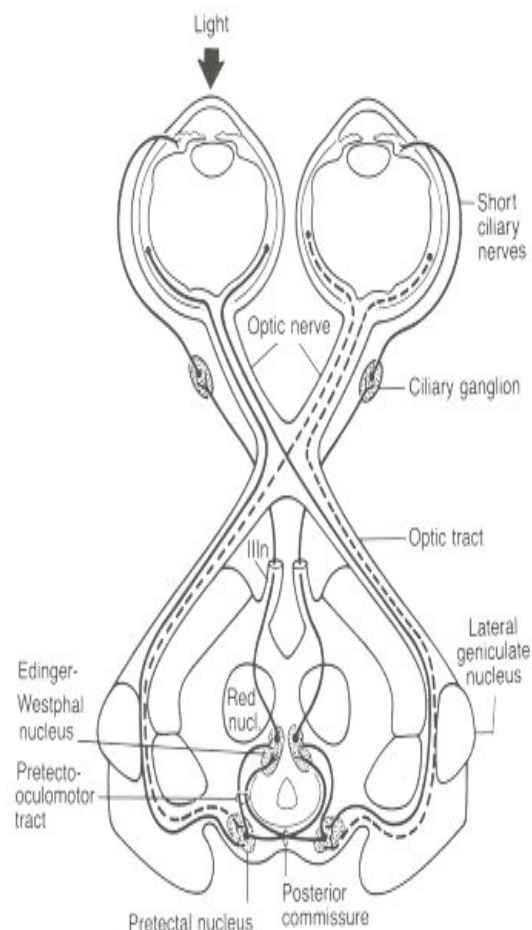
1)- Light reflex :-

* Def.:- exposure of one eye to bright light with the other eye closed → constriction of the pupil on the same side (direct reaction) & constriction of the pupil on the other side (consensual reaction).

* Pathway :-

- light stimulates rods & cones → axons of ganglion cells → optic nerve (*afferent*) → 53% of fibers decussate in optic chiasma & 47% of fibers remain ipsilateral → optic tract → olivary pretectal nucleus in the midbrain (*pretectal nuclei are 4 → olivary, anterior pretectal, posterior pretectal & nucleus of optic nerve*) where they synapse (*center*).

- Postganglionic fibers are small, of low conducting velocity, hemidecussate via posterior commissure & synapse in medial & anterior parts of EWN (which



is a column of small longitudinal cells in dorsal part of oculomotor nuclear complex).

- EWN receives equal impulses from both optic nerves due to hemidecussation.
- Efferent fibers from EWN pass in the superficial layer of CN III → inferior division (*efferent*) → nerve to inferior oblique → ciliary ganglion → postganglionic fibers pass through short ciliary ns → enter the globe → supply constrictor pupillae & ciliary ms.
- CN III palsy in tumours affect peripheral part → light reflex is affected.
- CN III palsy in DM & hypertension affect central part → light reflex is not affected.
- Direct reflex is longer in duration than consensual if using special techniques & when light is exposed to temporal visual field.

• Light reflex in visual pathway lesions :-

a)- *Optic nerve lesion :-*

- loss of direct reaction on the same side.
- loss of consensual reaction on the opposite side.

b)- *Optic chiasma lesion :-*

- median lesion → bitemporal hemianopic lesion.
- bilateral peripheral lesion → binasal hemianopic lesion.

c)- *Optic tract lesion :-*

- distal portion → contralateral hemianopic paralysis.
- proximal lesion → normal light pupillary reflex.

d)- *Superficial brachium & tectum lesion :-*

- contralateral hemianopic paralysis.

e)- *Central decussation lesion :-*

- loss of light reflex on both sides with preservation of near reflex.

f)- *Between central decussation & EWN at one side :-*

- loss of direct & consensual reaction on the same side.
- preserved direct & consensual reaction on the other side.

g)- *EWN, CN III & Ciliary ganglion lesion :-*

- loss of direct & consensual reaction on the same side.

N.B. for every 1 axon leaving the ciliary ganglion for light reflex there are 30 axons leaving for near reflex.

- Clinical applications of light reflex :-

- a)- Light - near dissociation :-

- normally the amplitude of pupillary response to light equal to amplitude of pupillary response to near.

- Abnormalities :-

- 1)- *Midbrain lesion in pretectal area :-*

- light reflex response ↓ while near reflex response is normal.
 - pupils are mid-dilated or dilated & unequal bilaterally.

- 2)- *Argyll-Robertson pupil :-*

- causes :- neurosyphilis, DM, DS & chronic alcoholism.

- lesion :-

- * in afferent pathway :-

- tumour, trauma & inflammation e.g. \$ affecting the retina, optic nerve, optic tract & chiasma.
 - lesion in pretectal area sparing the ventral part (contain near reflex fibers).

- * in efferent pathway :-

- CN III lesion when regeneration (apparent regeneration) near reaction is restored.
 - lesion in the ciliary ganglion.

- Manifestations :-

- * light reflex response ↓.



Figure. Argyll Robertson pupil.

- * near reflex response is normal or rapid.
- * pupils are small & asymmetrical (unequal).
- * poor response to mydriatics.

b)- Pupillary constrictor dysfunction (dilated pupil):-

1)- Dilated fixed pupil :-

- no response to light or near.
- causes → midbrain lesion (EWN).
 - CN III lesion e.g. carotid or post. communicating artery aneurysm.
 - ciliary ganglion or short ciliary ns lesion.
 - iris damage (posterior synechia).
 - drugs e.g. atropine.
 - death.

2)- Adie's pupil :-

- dilated, tonic & hypersensitive pupil.
- poor light reflex & good near reflex.
- rapid constriction by near & dilate slowly on looking to far.
- cause :- lesion in ciliary ganglion & short ciliary ns.
- sphincter is hypersensitive to low concentrations of pilocarpine 0.12% (characteristic denervation hypersensitivity).
- light reflex rarely recover, but near reflex usually recovers 1:30.



*** Characters of light reflex :-**

- no fatigue, but retina adapts to continuous illumination.
- latency is 0.2 sec. due to multiple synapses.
- duration till mxm constriction is 0.94 sec.
- mxm rate of constriction is 5 times rate of dilatation.
- motor discriminative activity is 0.95 sec., smallest difference in time between two lights cause pupillary constriction.
- visual discriminative activity :- smallest difference in light intensity between two lights which can be detected by patient & measured by pupilloscope.

* Factors affecting light reflex :-

a)- Stimulus factors :-

- light intensity :- $\downarrow$ intensity $\rightarrow \uparrow$ latency $\rightarrow$ slow reaction.
- duration of exposure :- short time $\rightarrow$ short reaction.
- wave length :- in dark $\rightarrow$ more constriction for green light.
 - in light $\rightarrow$ more constriction for yellow light.
- frequency :- no response for > 5 Hz.

b)- Receptor factors :-

- portion of the retina stimulated :- fovea lead to more response than peripheral retina when stimulated.
- area of the retina stimulated :- $\uparrow$ area $\rightarrow$ $\uparrow$ response (paramacular area is more sensitive in dark adaptation while macular area is more sensitive in light adaptation).
- adaptation :- rapid $\uparrow$ illumination $\rightarrow$ marked reaction.
 - slow $\uparrow$ illumination $\rightarrow$ slow & little reaction.
- age :- light reflex $\downarrow$ in old age due to sclerosis of the sphincter.

2)- Near reflex :-

- Def. :- when the eyes are directed from far to near object, a triad will occur :-
- 1)- Accomodation :- contraction of the ciliary ms.
 - 2)- Convergence :- contraction of medial recti.
 - 3)- Miosis :- contraction of sphincter pupillae ms.

- Pathway :-

- *Stimulus* :- blurring of vision.
- *Receptors* :- rods & cones.
- *Afferent* :- retina → optic nerve → optic chiasma, where nasal fibers crosses to the opposite side & temporal fibers remain uncrossed → optic tract → LGB → optic radiation → area 17 in occipital lobe → area 18 & 19 → area 8 in frontal lobe → fibers descend in internal capsule to CN III nuclei in midbrain → EWN of both sides.

- *Center* :- EWN.
- *Efferent* :- through CN III to :-
 - 1)- medial recti :- fibers come from CN III not EWN.
 - 2)- ciliary ganglion :- where relay occur & postganglionic parasympathetic fibers pass through short ciliary ns to ciliary ms & sphincter pupillae ms.
 - 3)- accessory ganglion :- where relay occurs & postganglionic parasympathetic fibers pass to sphincter pupillae ms.

- Clinical applications :-

- near reflex is present in uncorrected myopia & in very old persons who lost their accommodation.
- near reflex is absent in paralysis of convergence where accommodation is normal.
- constriction of the pupil is equal on both sides even if one eye is covered or has defective vision.

N.B. Accommodation, convergence & miosis are independent of each other & can be dissociated from each other by using prism.

The 3 components are triad & under supranuclear control by visual cortex (area 8 in frontal lobe).

3)- Orbicularis reflex :-

- Def. :- forcible closure of the lids against resistance by fingers to make lids opened → slight miosis on the same side.
- Pathway :- *afferent* → unknown.
 - *center* → motor cortex.
 - *efferent* → 3rd CN.
- It's of no clinical value.
- May be due to :-
 - a)- partial innervation of orbicularis by fibers from 3rd CN nucleus.
 - b)- irritation of EWN by irritating impulses from 7th CN nucleus.

4)- Trigeminal reflex (Oculo-sensory reflex):-

- Def. :- irritation of trigeminal nerve endings which supplies anterior segment, cornea, conj. & eyelids.
- * for short time → pupillary dilatation.
- * for long time → pupillary constriction.
- Causes :- may be due to axon reflex (antidromal effect) → dilatation of iris BVs → miosis. Or it may be due to stimulation of 5th CN → 5th CN ganglion → MLB → 3rd CN nucleus → 3rd CN.
- The actual cause is unknown but cutting of 5th CN behind the trigeminal ganglion → miosis persist.

II)- Reflexes dilating the pupil :-

1)- Withdrawal of light :-

- depends on stste of adaptation of the retina.
- results from :- relaxation of the sphincter pupillae.
 - active contraction of the dilator pupillae.
 - passive elasticity of iris tissue.
- pathway :- correspond to that of light reflex upto brachium (pretectal nucleus) of superior colliculus then dilator fibers descend in the tectospinal tract → cilio-spinal center of Budge.

2)- Painful stimulation :-

- due to sympathetic stimulation & parasympathetic inhibition.

3)- Vagotonic pupillary reflex :-

- inspiration → pupillary dilatation.
- expiration → miosis.

4)- Psychosensory motor reflex :-

- due to excitation of all sensory ns except trigeminal e.g. fear & anxiety.
- there is stimulation of EWN & sympathetic system.
- it's probably cortical in origin.

5)- Cochlear stimulation :-

- bilateral dilatation preceded by constriction on hearing sudden noise.

6)- Vestibular stimulation :-

- by head rotation or caloric stimulation → stimulation of sympathetic fibers which pass in middle ear → pupillary dilatation during stimulation & for short time after stoppage of stimulation (absent after radical mastoidectomy).

* Clinical applications on dilating pupillary reflexes (Horner's \$):-

- Cause :- lesion in the sympathetic supply to head & neck on same side i.e. damage to sympathetic chain.

- Clinically :-

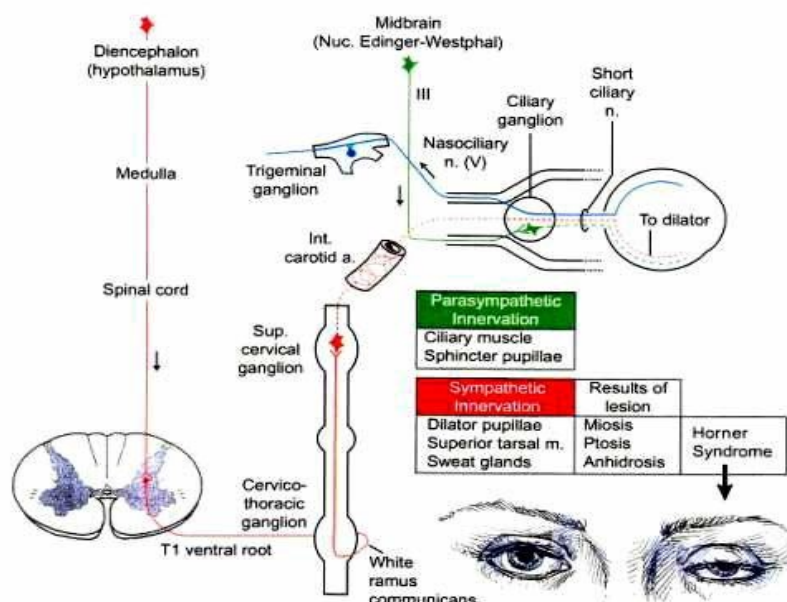
a)- *mild ptosis* :-

- due to paralysis of Muller's ms.

b)- *mild elevation of the lower lid* due to paralysis of lower lid retractors.

c)- *miosis* :- but react to light & near normally.

d)- *anhidrosis* :- but only if the



lesion is below the superior cervical ganglion & this is due to nerve fibers of the face derived from plexus around external carotid artery (impairment of sweating in ipsilateral face & neck).

- Confirming tests :-

a)- Cocaine 4% drops in both eyes :-

- normal pupil → dilate.
- affected pupil → no dilatation.

b)- Exposure to dark :-

- slow dilatation of affected pupil in relation to the normal pupil.



c)- Hydroxyamphetamine 1% in both eyes :-

- preganglionic lesion → both pupils will dilate.
- postganglionic lesion → affected pupil will not dilate.

d)- Adrenaline 1/1000 solution in both eyes :-

- preganglionic lesion → no dilatation of both pupils due to rapid destruction of adrenaline by MAO enzyme.
- postganglionic lesion → dilatation of the affected pupil due to absent MAO enzyme.

*** Abnormal pupils :-**

I)- Afferent pupillary defect :-

- causes :- macular disease, optic nerve disease, RD & CSR.
- loss or weak direct light pupillary reflex.
- when other eye is stimulated → consensual reaction on the affected side.

II)- Efferent pupillary defect :-

a)- Dilated fixed pupil :-

- causes :- mentioned before.
- consensual reaction on the other side is preserved.

b)- Aberrant 3rd CN regeneration :-

- e.g. after recovery from posterior communicating artery aneurysm.
- lid retraction on adduction or depression.
- pupil constrict on adduction, depression or elevation.

c)- *Cyclic oculomotor spasm* :-

- due to congenital 3rd CN palsy.
- there's intermittent spasm of all 3rd CN components :-
 - 1)- light-near dissociation.
 - 2)- Horner's \$.
 - 3)- unequal pupils i.e. anisocoria.

3)- The Cornea :-

- *Permeability.*
- *Deturgescence.*
- *Transparency.*
- *Sensitivity.*
- *Metabolism.*
- *Healing.*
- *Vascularization.*

I)- Corneal Deturgescence (partial dehydration) :-

- the cornea is 80% hydrated, despite this, the corneal stroma imbibes water if it's placed in a saline solution due to high content of glucosaminoglycans (GAGs) which form the stromal fibers.
- transport of water from the stroma is a two way process

a)- Endothelial pump :-

- it determines the level of hydration of GAGs.
- Na^+ & HCO_3 are transported across the endothelium from the stroma to the aqueous mediated by Na^+/K^+ ATPase & carbonic anhydrase enz.

b)- Epithelial transport :-

- Na^+ moves from the tear into the epithelium by passive diffusion down a concentration gradient, but from epithelium into the stroma active transport is required via Na^+/K^+ ATPase to which Cl^- transport in the opposite direction is coupled, Cl^- pump is modulated by several receptors including β -adrenergic receptors coupled to the adenylate cyclase.

N.B. Corneal stroma is still hydrophilic because of excess Na^+ ions attached to mucopolysaccharides molecules.

*** Importance :-**

- essential for corneal transparency.

*** Factors affecting corneal dehydration :-**

a)- *Evaporation from corneal surface.*

b)- *Negative stromal swelling pressure :-*

- normally -50 mmHg.
- minimal at PH 4 (iso-electric point of tissue).
- excised cornea $\rightarrow$ 78% hydrated.
- when placed in aqueous media $\rightarrow$ 98% hydrated because the cornea imbibes water.

c)- *Barrier function of limiting layers :-*

- both epithelium & endothelium act as a semipermeable membrane that create a barrier to diffusion of electrolytes & flow of water.
- epithelium offers most resistance to flow of water.
- endothelium offers its barrier function through Ca^{++} ions mechanism & zonulae occludens.

d)- *Endothelial pump mechanism :-*

- it's formed of enzymes in the plasma membrane that catalyze the movement of ions from stroma to aqueous thus creating an osmotic gradient that draws water out of the stroma.

- Na^+ & HCO_3^- transported across the endothelium from stroma to aqueous is mediated by Na^+/K^+ ATPase & carbonic anhydrase enzymes.

e)- Intraocular pressure :-

- 50 mmHg or higher result in corneal edema which is reversible.
- in infants, high IOP result in corneal enlargement, corneal edema & breaks in Descemet's membrane.

f)- Metabolic activity of all corneal layers :-

- metabolic poisons :- iodoacetate inhibit anaerobic glycolysis & most of oxidative (aerobic) metabolism when injected into AC of rabbit (80% increase in corneal hydration), also Ouabain (Na^+/K^+ ATPase inhibitor) produce corneal overhydration when injected into AC.
- $\downarrow$ temperature $\rightarrow \downarrow$ metabolic activity $\rightarrow$ corneal hydration.

II)- Corneal permeability :-

*** Importance :-**

- regulate corneal hydration which is essential for maintenance of corneal transparency.
- regulate diffusion of nutrients, O_2 & metabolic products from tear film & aqueous.
- transport drugs across the cornea to aqueous.

*** Mechanism :-**

1)- Passive mechanism :-

a)- Diffusion :-

- molecules move across epithelium & endothelium (act as semipermeable membranes) to achieve equal concentration on the two sides (stroma on one side & tears or aqueous on the other side).

b)- Phase solubility (dual nature of corneal permeability):-

- the lipid content of the epithelium & endothelium is 100 times $>$ that of the stroma.

- epithelium & endothelium are more permeable to lipophilic (e.g. fluorescein & electrolytes) > hydrophilic substances.
- corneal stroma is more permeable to hydrophilic substances that pass between collagen fibers slightly hindered by mucopolysaccharides.
- drugs possessing both lipid & water solubility (i.e. biphasic) penetrate the cornea more readily.

c)- *Drug related factors :-*

* Solubility & molecular size :-

- lipid soluble molecules pass through the phospholipid portion of the cell membrane by dissolving in it & diffusing through it.
- water soluble molecules of size < 4 Angstrom (MW < 500) can pass through intercellular pores.

* Ionic charge :-

- only non-ionized substances can penetrate the lipid cellular epith. & endothelium.
- ionized substances can traverse the stroma easily.
- drug should be in both ionized & non-ionized form to penetrate the cornea.
- the non-ionized molecule penetrates the epithelium then dissociates to ionized form which passes through the stroma then associates to non-ionized form to traverse the endothelium.

* PH & stability :-

- many eye drops are weak acids or bases.
- pilocarpine is more stable at PH 6.5 than 7.4, this ensures drug stability & tear layer can return rapidly to physiologic PH level (7.4) thus prevent ocular irritation.

* Concentration :-

- high drug concentration → ↑ osmolarity → pull fluid across the conj. → diluting the drug in the tear film.
- addition of soluble polymers, soluble gels & ointment all used to prolong drug-cornea contact time.

* Viscosity :-

- ↑ viscosity of drug vehicle → ↑ ocular drug penetration, more rapid drug saturation & slow washout by tears.

* Wetting agent (↓ surface tension):-

- preservatives e.g. benzalkonium chloride act as wetting agent →
- ↑ ocular drug penetration.

2)- Active mechanism :-

a)- Endothelium pump :-

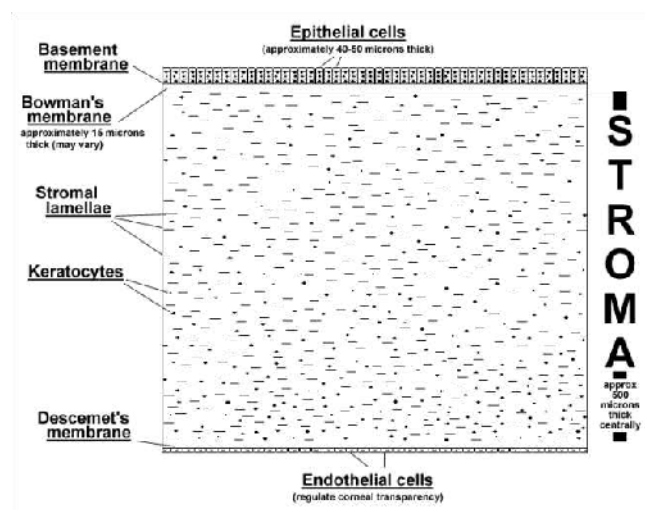
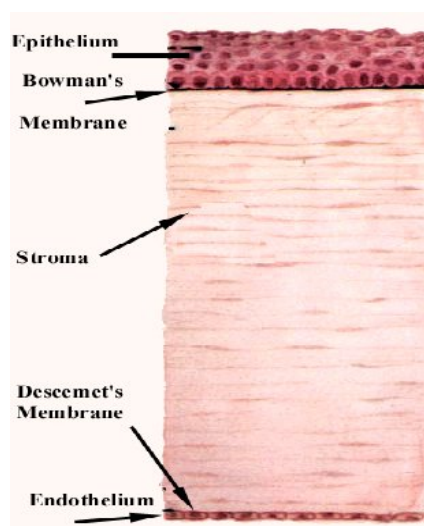
- it's formed of Na^+/K^+ ATPase & carbonic anhydrase enzymes in the plasma membrane that catalyze the movement of NaHCO_3 from stroma to the aqueous, thus creating an osmotic pressure that draws water out of the stroma.

b)- Pinocytosis :-

- dissolved macromolecules are fixed on the surface membrane of the endothelial cells forming vacuoles which move across the cytoplasm to be expelled out in the stroma.

III)- Corneal transparency :-

- light scattering in opaque tissue is due to the large disparity in RI between matrix components as collagen & glucosaminoglycans (GAGs).
- the cornea is a transparent tissue despite its cellular & extracellular matrix components which are of the same basic chemical composition as other tissues normally scatter light.



- How the cells & matrix components are organized within the tissue to ↓ the RI disparity :-

*** Maurice theory :-**

- arrangement of the collagen fibrils of uniform thickness form a lattice structure that scattering of light is eliminated by destructive interference from individual fibrils.

*** Goldmann theory :-**

- the stromal fibrils (being tightly & regularly packed together) are small with interference to light wavelength.
- fibril diameter is < 30 nm & the interfibrillar distance is 55 nm, for light scattering this distance must be > 200 nm.

*** Causes of corneal transparency :-**

a)- Anatomical construction :-

- uniform regularly arranged non-keratinized epithelium.
- absence of BVs.
- non-myelinated nerve fibers.
- closely packed corneal lamellae (compactness) which are uniform in size, equally spaced & running parallel to each other forming a lattice structure eliminating light scattering by mutual interference from individual collagen fibrils.
- single layer of homogenous closely packed endothelial cells.

b)- Physiological properties :-

- uniform RI.
- Deturgescence :- lamellae are not fully hydrated. The endothelial pump formed of enzymes (Na^+/K^+ ATPase & carbonic anhydrase) in the plasma membrane that catalyze movement of ions from stroma to aqueous thus creating an osmotic gradient that draws water out of the stroma.

IV)- Corneal sensitivity :-

a)- Innervation pattern :-

- 70 - 80 bundles of nerve filaments penetrate into the cornea in 3 planes : sclera (mainly), episclera & conjunctiva.
- they lose their myelin sheath within 1 mm & forms a plexus with twigs & loops whose branches are distributed throughout the stroma from Descement's membrane to Bowmann's membrane.
- 2nd plexus is formed under the epithelium, from it fine twigs enter the epithelium after lose their Schwann cells covering running between the epithelial cells.
- innervation density is greatest across the corneal center (5 mm in diameter) & ↓ gradually towards the limbus.
- **Sympathetic innervation** :- reach the cornea via the posterior ciliary ns & distributed in the stroma.
- **Nerve-end organs** :-
 - 1)- 1st type :- contain many mitochondria, neurofilaments & neurotubules. They are present in intraepithelial & stromal axons.
 - 2)- 2nd type :- few mitochondria, neurofilaments & neurotubules. They are present in intraepithelial plexus.

b)- Pathway & reflexes :-

* 1st neuron :-

- small cells in the trigeminal ganglion.
- peripheral dendrites come from the cornea through long ciliary n.
→ ciliary ganglion without relay → nasociliary nerve → ophthalmic n.
- axons pass through the sensory root of the 5th CN to the trigeminal nucleus in the pons.

* 2nd neuron :-

- trigeminal nucleus in pons (main sensory nucleus → touch, spinal nucleus → pain & temperature).
- axons cross to the opposite side to reach the thalamus through the trigeminal lemniscus.

*** 3rd neuron :-**

- postero-medial ventral (PMV) nucleus of the thalamus.
- axons pass through the internal capsule to reach the face region in the lower part of the sensory area in the post-central gyrus in the parietal lobe.

*** Reflexes :-**

1)- *Blinking (corneo-palpebral):-*

- afferent → 5th CN.
- efferent → 7th CN.
- center → basal ganglia.

2)- *Irido-constrictor :-*

- efferent → 3rd CN.

3)- *Vasodilator :-*

- irritation of the eye → redness.
- efferent → sympathetic vasomotor fibers.

4)- *Lacrimal :-*

- arc of innervation of the lacrimal gland.
- efferent → 7th & 9th CNs.

5)- *Axon reflex :-*

- mustard oil drops produce miosis & VD.
- disappear after topical anaesthesia.
- persist after 5th CN neurectomy behind the Gasserian ganglion.

6)- *Trophic effect :-*

- 5th CN neurectomy in front of Gasserian ganglion → keratitis due to sympathetic nerve with its vasomotor effect joins the nerve in front of the ganglion.

c)- Modalities :-

*** Pain :-**

- sensitivity to pain ↑ from periphery to the center which is richly supplied by free nerve endings.
- the horizontal meridian is more sensitive than vertical & temporal > nasal.

*** Touch :-**

- proved by presence of touch with absence of pain after cutting the trigeminal tract in the medulla to relieve pain in trigeminal neuralgia.

*** Cold :-**

- cold receptors are deeper than pain & touch receptors.
- patient may feel cold in his eye after topical anaesthesia.
- No heat receptors in the cornea, they are present only in lid margin & caruncle.

d)- Test :-

- aesthedimeter of Cochet & Bonnet :- nylon filaments are 0.12 mm in diameter contained in a pencil like handle, the length & the pressure exerted can be changed.
- the normal threshold is 4.5 cm length or 16 mg/mm² pressure.

V)- Corneal vascularization :-

*** Normal cornea is avascular because :-**

- a)- compactness of the stroma is mechanical obstacle to penetration of new vessels (stromal edema precedes vascularization but some edemas are not followed by vascularization).
- b)- rich mucopolysaccharide content is a barrier to neovascularization (cartilage is also rich in MPS content & is avascular).

*** Pathological neovascularization occurs experimentally by :-**

- a)- corneal injury, wound or burn.
- b)- ↓ of vit. B₂ or ariboflavinosis, ↓ vit.A or essential aminoacids.

*** In Rabbits, corneal vascularization occurs in the following steps :-**

- a)- 3rd day → engorgement of limbal capillaries & venules.

- b)- 4th day → rupture of aneurysms producing hge in the stroma.
- c)- 6th day → fine capillaries invade stroma.

* Mechanism of vascularization :-

- unknown.
- corneal lesion produces X - factor that either stimulates :-
 - a)- limbal BVs proliferation.
 - b)- anti-vascularization barrier.
- Ashton claims that corneal trauma produces hypoxia that lead to accumulation of lactic acid that stimulates vascularization (against → hyperoxygenation has no effect on vascularization).
- Payrau claims that lesion produces a substance that diffuses to the limbus, leads to rupture of mast cells liberating histamine that leads to VD, ↑ permeability & corneal edema that allows invasion by new vessels (against → antihistaminics has no effect on corneal vascularization).

VI)- Corneal metabolism :-

* Definition :-

- metabolism is a series of chemical processes mediated by enzymes by which energy is obtained & utilized for growth, normal functions & in certain abnormal conditions.

* Importance :-

energy is needed for :-

- maintenance of dehydration & transparency (metabolic pump).
- resynthesis of corneal tissue & healing after injury as wounds & ulcers.
- various cellular activity.

* Requirements :-

- carbohydrates :- glucose mainly & glycogen which is stored in epithelium & used in emergency e.g. wounds.

- O_2 :- O_2 consumed by the cornea is taken in by the epithelium & endoth. & expressed as QO_2 (in epith. & endoth. > stroma).

* Sources of substrates :-

a)- Glucose :-

- aqueous is the main source.
- limbal capillaries.
- tear film (insignificant).

b)- O_2 :-

- air solved in the tear film.
- aqueous supply the endothelium.
- cornea consumes $1\mu\text{L}$ / hour dry weight.

* Factors affecting corneal metabolism :-

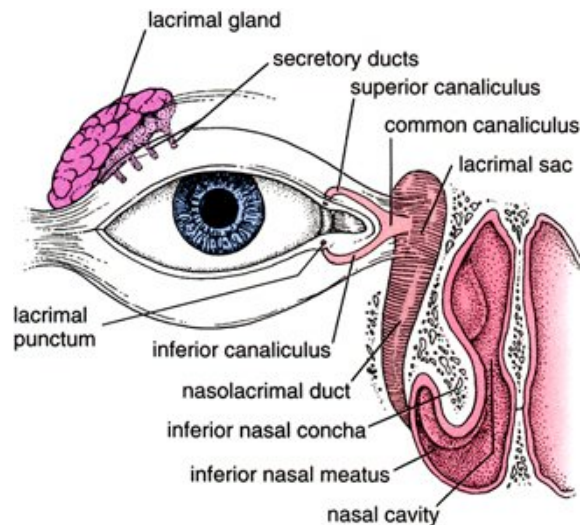
- *anatomical integrity* :- precorneal tear film, aqueous & intact epithelium is essential for supply of H^+ carriers.
- *O_2 deficient from air* $\rightarrow$ inhibit metabolism $\rightarrow$ corneal edema.
- *metabolic poisons* :- ouabaine (ATPase inhibitor) & iodoacetate (inhibit Krebs's cycle).

* Metabolic pathways :-

- *Glycolysis (anerobic)*:- mainly in the stroma (cells contain no mitochondria nor enzymes for Krebs's cycle) & in the epithelium under O_2 lack conditions (glucose $\rightarrow$ 2 lactic acid + 2 ATP).
- *Krebs's cycle (aerobic)*:- in epithelium, endothelium & keratocytes (glucose $\rightarrow$ CO_2 + H_2O + 38 ATP).
- *Hexose monophosphate (Pentose) shunt*.

4)- The Lacrimal Apparatus :-

- It consists of secretory & excretory parts.



I)- Secretion of tears :-

- 0.5 - 1.25 gms or ml is secreted over 16 hrs waking period.
- premature infants fail to secrete tears, while newborn babies secrete tears in the 1st 24 hrs.

* Types of tear secretion :-

a)- Basic secretion :-

- by accessory lacrimal glands, goblet cells & tarsal glands.
- needs no stimulus & no innervation.

b)- Reflex secretion :-

- by main lacrimal gland.
- controlled by sympathetic & parasympathetic (7th CN) supply.

1)- Sympathetic :-

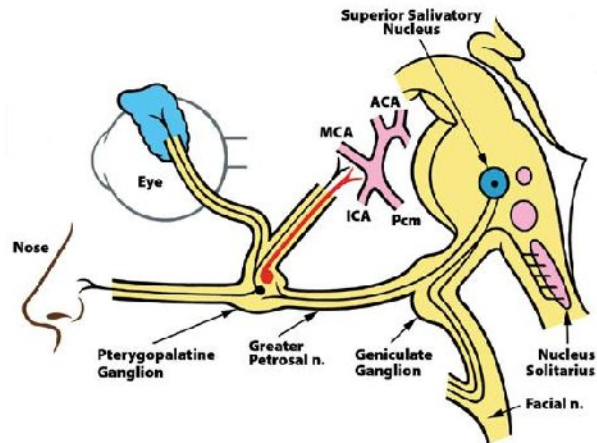
- act through vasomotor constriction or dilation.
- non-medullated nerve fibers from the internal carotid plexus reach the gland either around the lacrimal artery or as nerve of pterygoid canal to sphenopalatine ganglion → zygomatic nerve → lacrimal gland.

2)- Parasympathetic :-

- from superior salivary or lacrimatory nucleus in the brain stem → nervus intermedius (sensory root of facial) → greater superficial petrosal nerve → join nerve of pterygoid canal → relay in sphenopalatine ganglion → postganglionic fibers → zygomatic nerve → lacrimal gland.

* Afferent stimulus for reflex tearing :-

- 1)- optic nerve.
- 2)- trigeminal nerve.
- 3)- facial nerve (sensory part):-
taste & peppery food.
- 4)- synkinesis with vagus &
glossopharyngeal nerves :-
tearing with yawning, coughing or
vomiting.
- 5)- Psychic :- with emotions.



* Measurement of reflex tearing :-

- flow of tears can be Schirmer test or fluorophotometry, it's less in anaesthetized eye (0.3 - 1.8µl/min.).
- Schirmer test : after topical anaesthesia, less than 15 mm wetting is abnormal.

* Turn-over rate of tears :-

- is 12 - 16%/min. → ↑ by chemicals or inflammation → diluting topically applied medications.

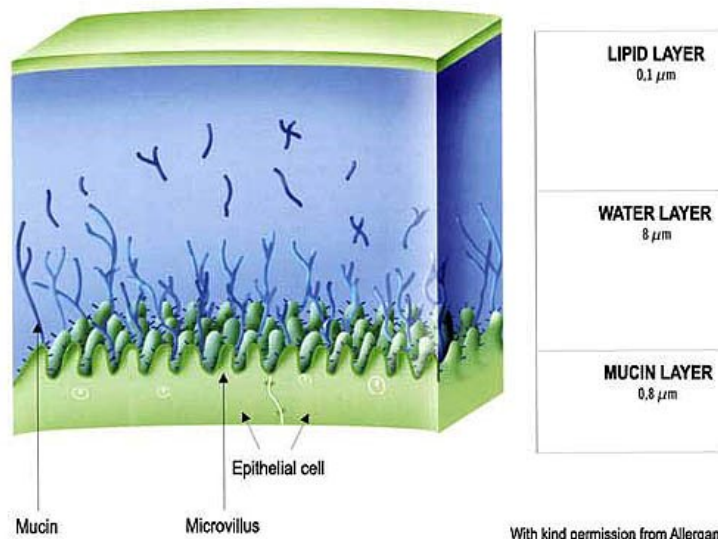
* Pharmacology :-

- ↑ secretion by parasympathomimetics.
- ↓ secretion by parasympatholytics (e.g. atropine), phenothiazine derivatives, antihistaminics & ganglion blocker agents.
- tear film stability (i.e. tear film doesn't fall by gravity) is improved by oral bromhexine.
- sympathetic denervation sensitizes the gland to both sympatho- & parasympathomimetics due to ↑ cell permeability.
- parasympathetic denervation sensitizes the gland to pilocarpine not eserine.

* Tear film :-

- it covers the ocular surface.
- thickness $\rightarrow 6.5 - 7.5 \mu$.
- volume $\rightarrow 7.4 \mu\text{l}$ in unanaesthetized eye, $2.6 \mu\text{l}$ in anesthetized eye & $\downarrow$ with age.
- grossly visible at the lower lid margin.
- optically clear & continuously renewed.
- composed of ptns & mucoptns to maintain its wetting & viscosity necessary for health of the epithelium of the ocular surface.

TEAR FILM



* Parts :-

- *marginal tear strip* :- posterior to inferior lid margin, forms a tear meniscus confluent with pre-ocular & pre-corneal tear film, carries debris to puncta.
- *pre-ocular tear film* :- cover bulbar & tarsal conjunctiva.
- *pre-corneal tear film*.

* Functions :-

- optically $\rightarrow$ fill up irregularities in corneal epithelium.
- supply O_2 from air to cornea.
- remove desquamated cells, debris & FB.
- lubricant.
- antimicrobial $\rightarrow$ lysozyme & immunoglobulins.

* Layers :-

I)- Oily (lipid) layer :-

- thickness $\rightarrow 0.1 - 0.2 \mu\text{m}$.
- secreted by Meibomian, Zeis & Moll glands.

- melts at 35°C thus spreading on the aqueous layer.
- *functions* → optical.
 - prevent tear over flow (hydrophobic barrier).
 - retard evaporation.
 - lubrication of lid-ocular interface.

II)- Aqueous layer :-

- 98.2% of tear film.
- total solids is 18.7mg/ml : ptns, urea, ammonia, amino acids, histamine, glucose & electrolytes.
- PH 6.5 - 7.6.
- *functions :-*
 - a)- control osmotic flow of fluids between tears & cornea (K^+ , Na^+ & Cl^-).
 - b)- buffer tear PH (HCO_3^-) & specific tear pre-albumin.
 - c)- enzyme co-factors to control cell membrane permeability (Fe^{++} , Cu^{++} , Mg^{++} , Ca^{++} & PO_4).
 - d)- defensive functions : antimicrobial & antivirals.
- Na^+ level is as in serum.
- K^+ is 6 times > in serum.
- fasting glucose in tears is 3.6 - 4.1 mg%.
- after 100 gm oral glucose → it's > 11 mg% in diabetics.
- *Proteins :-*
 - a)- Specific tear pre-albumin (STP): acts as buffer for tear film.
 - b)- IgA :- act as defense mechanism.
 - ↑ in ocular inflammations.
 - c)- IgE :- ↑ in vernal catarrh.
 - d)- IgE - Ag → degranulation of mast cells → histamine release.
 - e)- Non - immunoglobulins :-
 - lysozyme : antimicrobial, useful indicator of tear dysfunction.
 - β - lysin : antimicrobial.
 - lactoferrin : antimicrobial, indicator of lacrimal function.
 - interferon : inhibit viral replication, species specific.
 - enzymes : for glucose & amino acids metabolism.
 - collagenase & antiprotease.
 - PG & histamine : ↑ in vernal catarrh & trachoma.
 - plasminogen activator.

III)- Mucoïd layer :-

- produced by goblet cells.
- 2 - 3 µl/day (1/1000 aqueous part).
- tear dysfunction :-
 - a)- ↓ production → avitaminosis A or conjunctival destruction.
 - b)- ↑ production → FB irritation & hyperthyroidism.
- functions :-
 - a)- coat the ocular surface by hydrophilic layer essential for spontaneous distribution of tears.
 - b)- stabilizes tear film by ↓ surface tension through interacting with lipid layer, ↓ interfacial tension between tear-epithelium & ↑ critical surface tension of cornea.
 - c)- traps exfoliated cells, FB or bacteria.

*** Tear dysfunction state :-**

- causes :-
 - a)- *tear film constituents imbalance :-*
 - result from ↓ or ↑ in aqueous, mucinous or lipid abnormality.
 - assessed clinically by → tear meniscus, excess lipid or mucus debris.
 - Rose bengal stain.
 - tear break-up time (BUT).
 - aqueous tear production via Schirmer 1 & 2.
 - basic secretion test.
 - tear lysozyme, lactoferrin & osmolarity.
 - impression cytology of the conjunctiva &/or conjunctival biopsy.
 - b)- *corneal surface irregularities.*
 - c)- *lid-globe incongruity.*

STAIN	CONSTITUENT STAINED
- Fluorescein	Epithelial surface breaks
- Rose bengal	Dead cells & keratin
- Methylene blue	Dead cells
- Alcian blue	Mucus

II)- Elimination of tears :-

* Evaporation :-

- 25% of secreted tears when eyes are opened (no evaporation when eyes are closed).
- evaporation $\rightarrow$ $\uparrow$ tonicity of precorneal tear film $\rightarrow$ absorb water from the cornea $\rightarrow$ corneal dehydration.

* Excretion :-

- the remainder of tears $\rightarrow$ lacrimal puncta $\rightarrow$ canaliculi $\rightarrow$ sac $\rightarrow$ NLD $\rightarrow$ nose.

- Mechanism :-

a)- **Passive** :- gravity & capillary attraction.

b)- **Active (lid movement = suction pump):-**

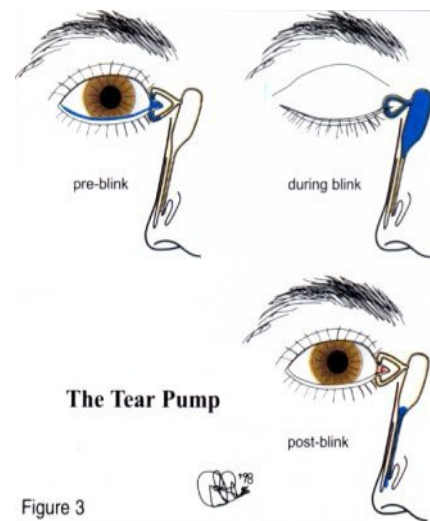
- *orbicularis contraction during lid closure* :-

dilate the canaliculi & draw the lateral wall of the sac laterally creating a -ve pressure $\rightarrow$ tears are directed to the sac.

- *orbicularis relaxation during lid opening* :-

ampulla of vertical part of canaliculus dilate & the sac collapse $\rightarrow$ tears are directed to the NLD.

- Folds or valves present in the NLD prevent air within the nose from being drawn up into the drainage system.



* Investigations of Epiphora :-

a)- **Jone's two stages test** :- instillation of fluorescein in the conjunctival sac & notation of its appearance in the nose.

- if no stain appear in the nose $\rightarrow$ irrigate the sac with saline :-
 - * if stained saline appears in the nose $\rightarrow$ upper segment is normal & lower segment failure.
 - * clear saline appears in nose $\rightarrow$ upper segment failure.
 - * no fluid appears at all $\rightarrow$ complete failure.

N.B. Upper segment (lid margin, puncta & canaliculi) - Lower segment (sac & duct).

b)- Dacryocystography :-

- radiographic appraisal of the emptying time for lacrimal drainage system by injection of contrast medium of known viscosity into the lacrimal sac.
- the normal sac will be emptied in < 15 min. & the normal duct within 30 min.
- any residual dye in the sac after 30 min. → functional block (even if the system was patent) as occurs in lacrimal pump failure due to orbicularis paralysis, or partial obstruction in the sac or duct relieved by dacryocystorhinostomy.

5)- Aqueous Humour :-

* **Def.:-** it's the intra-ocular fluid mainly formed by secretion from the non-pigmented ciliary epithelium (NPE).

*** Functions :-**

a)- Metabolism of avascular structures :-

- bring nutrients & carry away metabolites.

b)- Regulate IOP.

c)- Protective :-

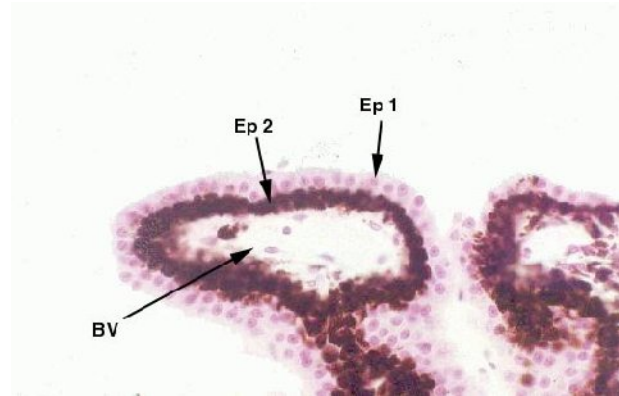
- ascorbic acid & glutathione protect against damaging effect of free radicals & peroxides that are continuously produced as by-products of metabolism.
- rapid removal of PG & catecholamines.
- plasmoid aqueous bring more defense mechanisms in cases of inflammation.

d)- Refractive medium.

* Formation of Aqueous humour :-

I)- Anatomical consideration :-

- AH is formed from the ciliary process (NPE).
- each ciliary process is formed of stroma covered by epithelium.
- the stroma is a CT having an arteriole from the circulus iridis major (hydrostatic pressure 50 - 60 mmHg).
- walls of the arterioles have pores (i.e. fenestrated).
- *Ciliary epithelium :-*



- 1)- two layers → inner non-pigmented (NPE) & outer pigmented (PE) arranged apex to apex, each has a basement or limiting membrane.
 - 2)- NPE is rich in mitochondria, Golgi apparatus & vesicles → evidence of ability to secrete.
 - 3)- cells have tight junctions.
- *Blood-Aqueous barrier :-* formed of :-
 - 1)- the capillary walls.
 - 2)- PE.
 - 3)- NPE & their BM.

II)- Mechanisms of aqueous formation :-

a)- Active secretion :-

- transport of substances across a biological membrane by cellular activity needing energy.
- energy is supplied by :-
 - 1)- *Oxidation-Reduction or exchange of electrons :-*
 - lead to difference in electrical potential across the ciliary epithelium.
 - H_2O from capillaries to stroma → dissociates into H^+ + OH^- .
 - H^+ return to blood in exchange of Na^+ .
 - OH^- goes across +ve NPE to aqueous to combine with Na^+ & CO_2 to form HCO_3^- .

2)- *Na⁺/K⁺ ATPase enzyme in NPE :-*

- actively transport Na⁺ with Cl⁻ & HCO₃.
- inhibition by ouabain → ↓ aqueous formation.

3)- *Carbonic anhydrase enzyme :-*

- catalyze the secretion.
- $H_2O + CO_2 \rightarrow HCO_3 + H^+$.
- inhibition by CAI e.g. acetazolamide → ↓ aqueous formation.

4)- *Adenylate cyclase in NPE :-*

- responsible for formation of cAMP.
- stimulation of this enzyme (by catecholamines & glycoprotein hormones)
→ ↓ aqueous formation.

b)- Passive secretion :-

- diffusion.
- dialysis → passage of water & electrolytes across a semipermeable membrane from solution to another hypotonic solution containing ptns.
- ultrafiltration.

*** Measurement of aqueous formation :-**

- the methods are indirect principles :-
 - a)- measuring a chemical substances rate of appearance in or disappearance from the aqueous e.g. dye (fluorescein), radioactive labelled e.g. ascorbate after IV injection.
 - b)- deriving the flow from formula after measuring :-
 - IOP.
 - episcleral venous pressure.
 - resistance to flow (or its reciprocal = facility : C).
- Flow = C (IOP - Episcleral venous pressure) = C (PO - PV).
Rate of formation is 2μl/min. (3 - 4 in rabbit).

*** Factors ↓ aqueous formation :-**

a)- General :-

- age.
- diurnal.
- exercise.

b)- Systemic :-

- ↓ BP.
- general anaesthesia (↓ BP).
- ↓ carotid blood flow.
- acidosis.
- hypothermia.
- adrenalectomy (as catecholamines → ↑ adenylate cyclase).

c)- Local :-

- pseudofacility (↑ IOP → ↓ aqueous formation).
- inflammation e.g. iridocyclitis.
- RD.
- choroidal detachment.
- retrobulbar anaesthesia.

d)- Pharmacological :-

- topical :- epinephrine → 30% ↓.
 - timolol (β -blockers).
 - guanethedine.
- systemic :- CAI (50% ↓).
 - hyperosmolarity.
 - cardiac glycosides.

e)- Surgical :-

- cyclo-dialysis.
- cyclo-diathermy.
- cyclo-cryotherapy.
- cyclo-laser photo coagulation.

*** Blood Aqueous Barrier :-**

- BAB is formed of tight junctions between ciliary epithelial cells & their BM .
- it hinders the passage of large molecules e.g. mannitol.
- slow passage of medium sized & water soluble substances.
- passes lipid soluble substances.

- Clinical application :-

- a)- use of hyperosmotic agents (mannitol) to dehydrate the eye (vitreous).

b)- rate of penetration of lipid soluble chloramphenicol is > gentamicin or penicillin in the undisturbed aqueous.

- Factors interrupting Blood aqueous barrier :-

a)- Traumatic :-

- mechanical :- corneal abrasions, blunt trauma, paracentesis, IO surgery & stroking iris.
- physical :- X-ray & atomic radiation.
- chemical :- alkali & irritants.

b)- Physio-pathological :-

- VD :- histamine, PG & sympathectomy.
- anterior segment inflammation or ischaemia.

c)- Pharmacologic :-

- cholinergic drugs.
- cholinesterase inhibitors.
- plasma hyperosmolarity.

* Plasmoid or Secondary aqueous :-

- when BAB is interrupted, the aqueous composition resembles plasma :-
 - a)- ptns ↑.
 - b)- cells appear → 1st leucocytes from blood, then lymphocytes.
 - c)- Antibodies which may be of diagnostic value e.g. toxoplasma.
- all these constituents help to protect the eye from the noxious agents although vision ↓ from turbidity.
- Steroids ↓ the ↑ permeability of the BAB.
- Flare can be measured roughly by slit lamp & graded 1,2,3,4+ or accurately by aqueous flare meter (Kowa).

* Characters of aqueous humour :-

I)- Physical properties :-

- *volume* :- 100 - 400 µl, or 3% of total volume of the globe, 4/5 in the PC.
- *specific gravity* :- 1.003 gm.
- *viscosity* :- near to water 1.025.
- *PH* :- 7.2 (less than plasma).
- *RI* :- 1.33 near that of the cornea.

- *osmotic pressure* :- 3 - 5 mmol/L > that of plasma.

II)- Chemical composition (similar to plasma if BAB is broken):-

a)- Proteins :-

- 0.02 gm/100ml (plasma 7 gm/100ml due to difficulty in passing BAB).
- 2/3 albumin & 1/3 globulin (as plasma) / amino acids :- similar to blood.
- Glutathione is more & has a protective function.
- aqueous IgG 5 mg/100ml.

b)- Enzymes :-

- carbonic anhydrase :- important for equilibrium between HCO_3 , H_2O & CO_2 .
- hyaluronidase :- important for aqueous outflow.
- lysozyme in inflammation.
- enzymes for fibrinolysis.
- for diagnostic purposes of retinoblastoma :- intracellular enzymes are released from damaged cells & can be detected in aqueous.

c)- Glucose :-

- less than in plasma.
- inositol is more (active secretion or from cornea).

d)- Urea, uric acid & creatinine :- less than in plasma.

e)- Lipids :- less than in plasma.

f)- Electrolytes :-

SUBSTANCE	PLASMA	AQUEOUS
Na^+	less	more
K^+ , Ca^{++} & PO_4	same	same
HCO_3 (rabbit) (man)		more less
Hormones (insulin)		less
PG		Less ($\uparrow$ in inflammation)
cAMP		same (by topical epinephrine $\rightarrow$ $\downarrow$ IOP).

g)- Gases :-

- O_2 :- 50 mmHg, important for corneal endothelium & lens.
- CO_2 :- 50 mmHg, important for HCO_3 formation.

h)- Metals :-

- Fe^{++}, Cu^{++} & Zn $\rightarrow$ as plasma.

i)- Vitamins :-

- act as co-enzymes.

III)- Substances present in excess in aqueous than in plasma proving its active secretion :-

- Ascorbic acid :- protective function.
- Glutathione :- protective function.
- Inositol.
- Lactic acid from anaerobic oxidation of cornea & lens.
- Hyaluronic acid from vitreous.

*** Outflow of Aqueous Humour :-**

- the normal rate of flow is $2\mu l/min$.

I)- Trabecular outflow (safety valve) conventional :-

- TM lies at the apex of the angle between the end of Descemet's membrane & CB.
- the part near the AC is the usual part with large pores & external to it is the corneo-scleral meshwork with smaller pores & is the site where most resistance to outflow lies.
- then aqueous pass to the canal of Schlemme, collector channels, aqueous veins & episcleral veins.
- because of presence of hyaluronic acid between the TM, perfusion of the eye with hyaluronidase $\uparrow$ outflow.
- because of origin of the longitudinal ciliary ms from corneo-scleral trabeculae $\rightarrow$ its contraction during accommodation $\uparrow$ outflow.
- the trabecular outflow is pressure dependant :-

$$F_{trab} = (P_i - P_e) C_{out} = (IOP - 10) \times 0.28.$$
- if the AC depth is kept constant $\rightarrow \uparrow IOP$ will $\downarrow F_{trab}$ (outflow).
- if the AC deeper $\rightarrow \uparrow IOP$ will $\uparrow F_{trab}$.

II)- Uveo-scleral outflow :-

- 25% (0.5 μ l/min.).
- independent of IOP.
- aqueous pass to CB & suprachoroidal BVs or through sclera.
- $\uparrow$ by atropine & $\downarrow$ by pilocarpine.
- in Acute glaucoma $\rightarrow$ both outflow channels are closed hence higher IOP than OAG where only trabecular outflow is $\downarrow$.
- in RD $\rightarrow$ uveo-scleral outflow is $\uparrow$ by passage of fluid from uvea through retinal breaks thus $\downarrow$ IOP.

*** Measurement of aqueous outflow :-****I)- Perfusion :-**

- experimentally $\uparrow$ the perfusion pressure until IOP becomes constant
the amount of inflow = amount of outflow.

II)- Tonography :-

- an electronic Schiotz tonometer is applied to the eye for 4 continuous minutes & IOP is recorded on a graph.
- mathematical calculations give the amount of aqueous outflow.

*** Factors affecting aqueous outflow :-****I)- $\uparrow$ outflow :-****a)- physiological :-**

- accommodation.
- parasympathetic stimulation.

b)- pharmacological :-

- hyaluronidase.
- cholinergic agents.
- adrenergic agents.
- progesterone.
- CAI.
- PG.

c)- surgical & pathological :-

- trabeculectomy.

II)- ↓ outflow :-**a)- physiological :-**

- relaxation of accommodation (↓ trabecular outflow although ↑ uveo-scleral outflow.
- ↑ venous pressure (episcleral & jugular venous pressure).

b)- pharmacological :-

- cycloplegic agents.
- steroids.
- estrogen.

c)- surgical & pathological :-

- trabecular swelling.
- inflammation of anterior segment.
- pigment, macrophages, fibrin & vitreous in the AC.

6)- Intra-Ocular Pressure

(IOP) :-

* Factors maintaining IOP :-

I)- Aqueous humour :-

- this is the main factor in regulating IOP which depend on :-

1)- Rate of aqueous formation :-

- 2 µl/min.

- rate of aqueous formation = ciliary artery pressure - IOP

$$\text{i.e. } F_{in} = (P_a - P_i) C_{in}$$

F_{in} → rate of aqueous formation.

P_a → ciliary artery pressure = 60 mmHg.

P_i → IOP.

- rarely ↑ aqueous formation → ↑ IOP due to compensatory ↑ in outflow (vide infra).
- ↓ aqueous formation → ↓ IOP.

2)- Rate of aqueous outflow :-

- mainly through TM.
- the volume of fluid / unit time that flow out through the TM is proportional to :-

a)- *The flow pressure gradient across the TM :-*

$$F_{\text{trab}} = (P_i - P_e) C_{\text{out}}$$

$P_i \rightarrow$ IOP

$P_e \rightarrow$ episcleral venous pressure

$C_{\text{out}} \rightarrow$ facility of outflow

- with $\uparrow$ aqueous formation $\rightarrow$ compensatory $\uparrow$ in outflow to maintain IOP, the mechanism of this safety valve may be physical or neurological evidenced by :-

* *presence of nerve receptors in the TM.*

* *Oculo-ocular reflex :- $\uparrow$ or $\downarrow$ of IOP in one eye $\rightarrow$ $\uparrow$ or $\downarrow$ of IOP in the other eye.*

* *vasomotor reflex via a hypothalamic center.*

* *Oculo-cardiac reflex :- $\uparrow$ IOP $\rightarrow$ $\downarrow$ HR $\rightarrow$ $\downarrow$ BP.*

* *Sympathetic stimulation $\rightarrow$ VC of uveal BVs $\rightarrow$ $\downarrow$ IOP.*

* *Trigeminal stimulation $\rightarrow$ PG release $\rightarrow$ intra-ocular VD $\rightarrow$ $\uparrow$ IOP.*

N.B. IOP $\uparrow$ about 1 mmHg for each 10 mmHg $\uparrow$ in mean brachial pressure.

b)- *The outflow facility :-*

- C_{out} = flow through the TM
- IOP - episcleral venous pressure
- mean value is 0.28.
- measuring outflow facility :-

* Perfusion :-

- the living or enucleated eye is cannulated & known volumes of fluid can be injected under a known pressure (P_i) & outflow facility can be calculated :-

$$\text{Flow rate} / (P_i - P_o) = 0.25 \text{ NL/min/mmHg.}$$

* Tonography :-

- its principle is pressing on the globe $\rightarrow$ initial $\uparrow$ of IOP followed by $\downarrow$.
- an electronic Schiottz tonometer is applied to the eye for 4 min.

during which IOP is measured every 15 sec. → a graph is obtained
 tables allow easy calculation of C based on the wrong assumption that
 ocular rigidity is average $\pm$.

* Suction cup :-

- it's applied to the perilimbal area → occlude the episcleral veins
 → ↓ trabecular outflow → ↑ IOP.
- by analysis of ↑ IOP & its subsequent decay, values of aqueous
 secretion & outflow facility can be calculated.

c)- Episcleral venous pressure :-

- normally 10 - 12 mmHg.
- ↑ of P_e as a result of ↑ venous pressure rarely → ↑ IOP as long as
 the outflow is normal.

II)- Crystalline lens :-

- the normal crystalline lens is :- 65 mg wt, ↑ by age upto 220 mg.
 - about 4 mm in thickness.
- Lens - induced glaucoma :- phacolytic (in hypermature cataract).
 - phacomorphic (in intumescent cataract).
 - phacoanaphylactic.

III)- Vitreous :-

- form 4/5 of the volume of the globe.
- rapid swelling → ↑ IOP.
- dehydration by osmotherapy → ↓ IOP.

IV)- Choroidal circulation :-

- the choroidal blood content plays a role in maintenance of IOP, this is
 proved by :-
- a)- enucleation → ↓ IOP, while obstruction of the retinal circulation has
 no effect.
- b)- rhythmic oscillation in IOP due to choroidal pulsations.
- c)- ligation of posterior ciliary arteries (short & long) → ↓ IOP.
- d)- ligation of the 4 vortex veins → ↑ IOP.

V)- Corneo-Scleral rigidity :-

- the relative ability of a given eye to expand when pressure is applied, depends on elasticity of cornea & sclera.
- ↓ rigidity (young & myopes) → IOP underestimation.
- hypermetropes & elderly → the reverse.

VI)- Pressure from EOM :-

- contraction → ↑ IOP.
- relaxation → ↓ IOP.

VII)- Neurological factors :-

- hypothalamic center control oculo-ocular reflex.
- parasympathetic stimulation → contraction of ciliary ms & sphincter pupillae → ↓ IOP.
- sympathetic stimulation → VC of ciliary BVs → ↓ IOP.
- oculo-ocular reflex (↓ IOP in one eye → ↓ IOP in the other eye).
- oculo-cardiac reflex (↑ IOP → ↓ HR → ↓ BP).
- trigeminal stimulation → PG release → VD → ↑ IOP.

*** Measurement of IOP :-**

I)- Manometry :-

- used in laboratory.
- a small hollow needle is inserted in AC.
- a reservoir of saline is raised so aqueous leave the eye & no saline enter the eye.
- this height → IOP in cm water.

II)- Tonometry :-

a)- applanation :-

- depends on the equation : $\text{Pressure} = \text{Force} / \text{Area}$.
- the pressure inside a flexible sphere can be closely approximated by knowing the force necessary to just flatten (applanate) a given area.
- we can determine the pressure by measuring the force necessary to flatten a fixed area (Goldmann) or by measuring the area flattened by a fixed force (Maklakoff).

- non-contact air puff tonometer → air jet flattens the cornea.
- Mackay - Marg tonometer → most useful in edematous or scarred corneas, spring mounted plunger 1.5 mm in diameter flattens.
- pneumatic applanation tonometer → records a graph.

b)- *indentation* :-

- a known force will indent a flexible sphere to greater degree if the internal pressure is ↓ than if the pressure is ↑ (Schiotz tonometer).

* Hypotony :-

- IOP < 8 mmHg → edema in retina, optic disc, choroid & cornea due to VD.

* Glaucoma :-

- IOP ↑ enough for long enough → characteristic visual field defect.

* Ocular hypertension :-

- ↑ IOP without field changes.

* Low tension glaucoma :-

- normal IOP + field changes.

7)- The Retina :-

- *Biochemistry of vision.*
- *Retinal metabolism.*
- *Visual acuity.*
- *Adaptation.*
- *Light sense.*
- *Colour vision.*
- *Macular function tests.*
- *Electrophysiology.*
- *Visual field.*

A)- Biochemistry of vision :-

I)- Retinal Pigment Epithelium (RPE).

II)- Photoreceptors :-

- rods & cones.
- outer segments contain visual pigments (purple colour) → bleaching by light → transparent colour.
- they are more sensitive to axial rays > peripheral rays (Stile Crawford phenomena).

I)- Retinal Pigment Epithelium (RPE):-

- Functions :-

a)- *Storage & metabolism of vit.A :-*

- vit.A comes to RPE from blood, digested outer segment of rods & cones, released from bleaching of visual purple.
- vit.A is stored in the form of retinyl-ester or bounded to specific ptn called Retinal Binding Ptn (RBP), this ptn carries vit.A in the blood.
- aldehyde & alcoholic form of vit.A are toxic to cell membrane.

b)- *Maintain Bloor-Retinal barrier :-*

- by tight junctions of the cells.

c)- *Melanine :-*

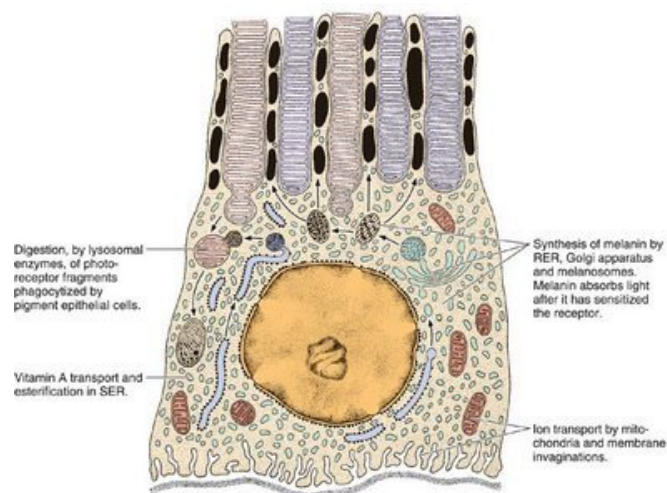
- prevent light reflection & absorbs stray light → clear vision.

d)- *Removal of free radicals :-*

- e.g. peroxides generated by photoreceptors during photochemical events.

e)- *Phagocytosis :-*

- of shedding materials of outer segments of photoreceptors & digest them in phagosomes.
- these materials are re-utilized by RPE or some of these materials accumulate in the form of



lipofuscin granules which are noticed in old age.

f)- *Maintenance of proper ionic & fluid environment* of subretinal space & production of trans-epithelial potential.

g)- *Biological filter* :-

- allow passage of glucose & vit.A.

h)- *Selective transport* of metabolites to & from retina.

i)- *adhesiveness to underlying sensory retina* by microvilli of RPE that surround photoreceptors + mucopolysaccharides secreted by RPE.

j)- *Metabolism* :-

- contain enzymes for 3 major pathways → citric acid cycle.
→ Kreb's cycle.
→ phosphogluconate pathway.
- esterifying vit.A by saturated fatty acids.
- prevent oxidation of fatty acids by vit.E → this ↓ formation of lipofuscin pigments.
- detoxification of free radicals & oxidized lipids.
- RNA synthesis.

II)- Phtoreceptors (photochemistry of vision):-

- vision is due to photochemical events (processes) & each visual pigment has a certain spectrum at which this pigment can absorb light.
- relative absorption of light of different wave lengths.
- maximum absorption of light (the most absorbed wave length).
- rods are very sensitive to light (bleaching of photoreceptors occurs even by a single photon).

N.B. vit.A is present in 3 forms → vit.A aldehyde (retinaldehyde).

→ *vit.A retinol.*

→ *vit.A ester (retinyl ester).*

- *vit.A is stored in the liver as retinyl ester or retinol.*

a)- Role of visual pigments in the process of vision :-

- there are 4 visual pigments in the photoreceptors → one type in rods called rhodopsin & 3 types in cones called iodopsin, each is specific for certain colour (red, green & blue).

N.B. pigments are aligned parallel to disc membranes, so perpendicular rays can act on it.

- all visual pigments have the same composition (11-cisretinaldehyde + ptn called opsin).

- the process of photochemistry :-

Rhodopsin → pre-lumirhodopsin



metarhodopsin ← lumirhodopsin



pararhodopsin → all transretinaldehyde

dehydrogenase ↓

all transretinol

esterification ↓ detoxification

all transretinyl ester

isomerase ↓

11 - cis retinyl ester



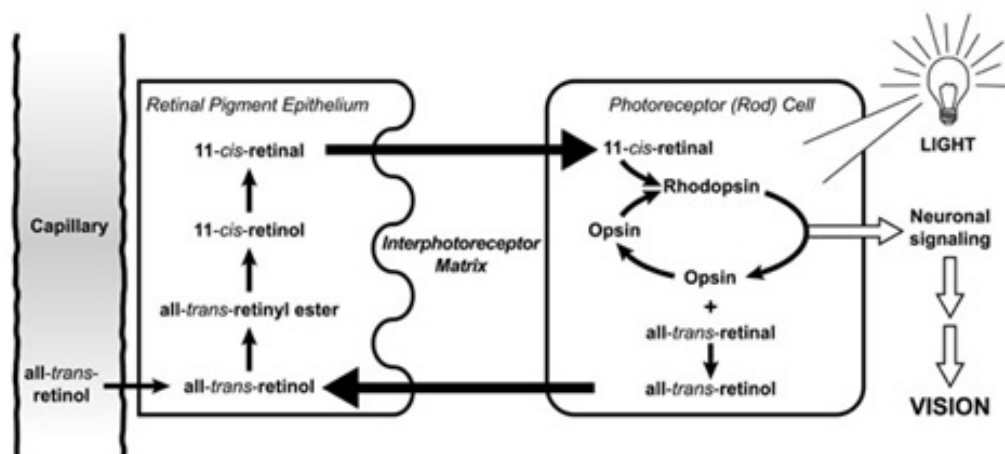
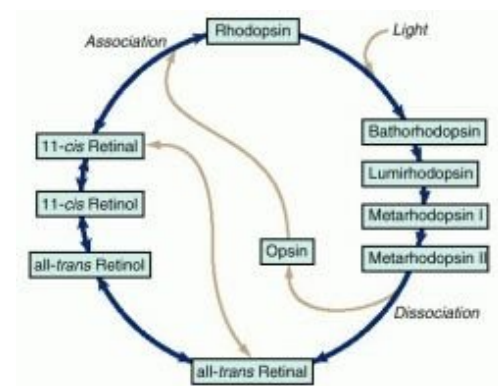
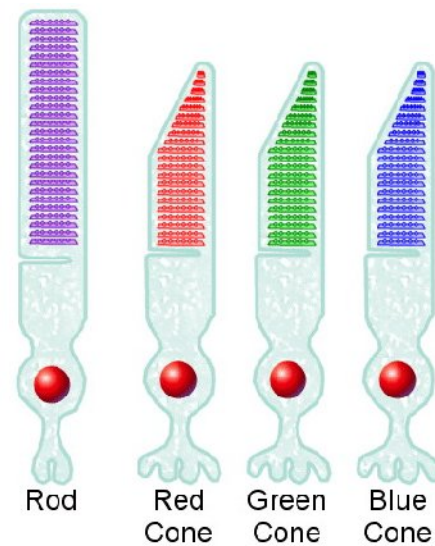
11 - cis retinol



11 - cis retinaldehyde



Rhodopsin



N.B. role of vit.A :- taken from blood as carotene → transformed into retinol in the wall of the intestine → blood → liver where it binds with aptn (RBP) → blood → RPE → outer segment of rods → transformed into retinine by retinine reductase → retinine + opsin → rhodopsin.

b)- Role of ion transport in the process of vision (electrical responses):-

1)- In dark (un-excited state):-

- neutralization of negativity on inner side of cell membrane of outer segments of rods.
- $\uparrow$ cGMP $\rightarrow$ $\uparrow$ Na^+ influx $\rightarrow$ depolarization $\rightarrow$ release of chemical transmitters at synapses $\rightarrow$ electrical impulses $\rightarrow$ brain $\rightarrow$ sense of darkness.

2)- In light (excited state):-

- $\uparrow$ negativity on inner side of cell membrane.
- $\downarrow$ cGMP $\rightarrow$ closure of Ca^{++} & Na^+ channels while Ca^{++} & Na^+ are still pumped out $\rightarrow$ $\downarrow$ intracellular Ca^{++} & Na^+ $\rightarrow$ hyperpolarization $\rightarrow$ stop release of chemical transmitters at synapses $\rightarrow$ sense of light.

c)- Evidence of photochemical nature of light :-

1)- Dark adaptation :- is photochemical in nature, evidenced by :-

- coinciding of maximum absorbing spectrum of rhodopsin (315 nm) with brightest wave length of human scotopic vision (500 nm) green-blue.
- one hour is needed for maximum adaptation for dark & reformation of rhodopsin.
- vit.A $\downarrow$ $\rightarrow$ night blindness.

2)- Duplicity theory of vision :- is photochemical in nature, evidenced by :-

- coinciding of maximum absorption of iodopsin (with wave length 570 nm) with human photopic visibility curve with maximum brightness at 500 nm (yellow-green).
- coinciding of maximum absorption of rhodopsin (with wave length 315 nm) with human scotopic visibility curve with maximum brightness at 500 nm (green-blue).

- Purkinje shift.

3)- Colour vision :- is photochemical in nature, evidenced by :-

- presence of 3 types of pigments with different maximum absorption wave length → blue 450 nm.
→ green 540 nm.
→ red 575 nm.

4)- Retinal sensitivity :-

- bleaching of rhodopsin → ↓ sensitivity.
- reformation of rhodopsin → ↑ sensitivity.

5)- Diseases :-

- retinitis pigmentosa :- ↓ vit.A → suffering of rhodopsin metabolism
→ night blindness.
- sensory RD :- ↓ formation of rhodopsin from vit.A in blood.

d)- Duplicity theory of vision :-

- it states that retinal function is totally different in day & night vision due to presence of 2 types of receptors:-

RODS	CONES
- in retinal periphery.	- in macula.
- responsible for scotopic vision.	- responsible for photopic vision.
- highly sensitive to light.	- less sensitive to light.
- little colour perception.	- good colour perception.
- little details perception.	- good details perception.
- convergence is very marked (several rods are associated together & send impulses to single bipolar cell) → high degree of spatial summation.	- no convergence of impulses (every cone discharge to single bipolar cell → single ganglion cell → single nerve fiber) → high degree of discrimination.

- Evidences :-

1)- dark adaptation curve composed of 2 parts :-

- 1st part → rapid, correspond to cone adaptation.
- 2nd part → slow, correspond to rod adaptation.

2)- the similarity between :-

- scotopic visibility curve & absorptive spectrum of rhodopsin.
- photopic visibility curve & absorptive spectrum of iodopsin.

3)- visual acuity :-

- $\uparrow$ with $\uparrow$ illumination leading to sigmoid curve.

4)- critical fusion frequency (CFF):-

- $\uparrow$ with $\uparrow$ illumination showing kink at point α (point of transition between photopic & scotopic vision).
- CFF is 10 in photopic vision.
- CFF is 1 in scotopic vision.
- CFF is highest at fovea (cones), $\downarrow$ at central 5° .

5)- ERG :-

- a-wave is related to rods & disappear in light adaptation.

6)- Colour blindness (absence of cone functions):-

- it's characterized by absence of breaks in the curves plotted to determine the retinal functions & log.
- intensity indicating that one mechanism only (rod) functioning e.g. :-
 - * dark adaptation curve $\rightarrow$ slow from the start without break.
 - * VA curve $\rightarrow$ continues with no breaks.
 - * CFF curve $\rightarrow$ slow from the start without breaks.
 - * central vision is impaired (i.e. presence of central scotoma).

7)- Night blindness :-

- dark adaptation is impaired.
- Purkinje shift phenomena is absent, but colour & central vision are normal (cones).

B)- Metabolism of the Retina :-

* Importance :- the basal metabolism of the retina is important for :-

- a)- breakdown & regeneration of visual purples.
- b)- active transport of metabolites to & from retinal parts.
- c)- production of A-ch. (neurotransmitter).
- d)- transmission of nerve impulses through synaptic layers of the retina.

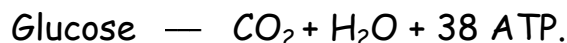
* Substrates :-

- a)- Glucose :- from blood.
- b)- Glycogen :- stored in Muller's cells & horizontal cells.
- c)- sugar content of vitreous is higher in region near degenerated retina than in region near healthy retina.
- d)- O_2 from blood flow to the retina.
- e)- retina has the highest rate of respiration in the body.

* Pathway of Glucose metabolism :-

a)- Citric acid cycle (aerobic):-

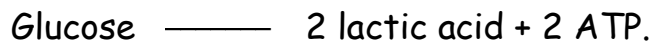
- in inner layers of the retina which have rich blood supply $\rightarrow O_2$.
- also inner layers contain ganglion cells which are rich in mitochondria $\rightarrow$ ATP & creatine phosphate for energy.



- this process also occurs in the photoreceptors.

b)- Glycolysis (anaerobic):-

- in outer avascular layers of the retina (diffusion from chorio-capillaries).



- ATP is the source of energy.



N.B. Pentose shunt doesn't occur in the retina, because it needs G6P which is not present in the retina (present only in the cornea & lens).

* Factors affecting retinal metabolism :-

a)- Light :-

- $\uparrow$ metabolism $\rightarrow \uparrow$ enzymes in mitochondria.
- $\rightarrow \uparrow$ nucleic acid metabolism.

b)- $\downarrow O_2$ (anoxia):-

- $\downarrow$ metabolism.
- rods are affected earlier than cones $\rightarrow$ peripheral field defect $\rightarrow$ blackouts.

- cones are late affected due to presence of yellow pigment in macula which help oxidative process in cones.

c)- Integrity of retinal cells :-

- degenerated retinal cells cannot utilize glucose.

d)- PH :-

- PH of light adapted retina is 7 & in dark adapted retina is 7.3.
- on exposure to light → change of PH of cones to acidic side (7) due to production of phosphoric acid by decomposition of cone substance (phosphate is important in metabolism).
- acidity leads to contraction of cones & expansion of RPE inbetween (like what occur in photochemical changes).
- rods are less affected.
- alkalosis produce the reverse.

e)- RPE :-

- storage of vit.A.
- isomerization of all-transvit.A to 11-cis vit.A (neosynthesis of photopigments).
- close contact between RPE & photoreceptors → production of membrane potential.
- selective passage of nutrients & metabolites between retina & choriocapillaries.
- phagocytosis of outer segments of photoreceptors.

N.B. Retinitis pigmentosa was thought to be due to enzymatic deficiency, this enzyme normally protect retinal cells from the injurious effect of metabolic by-products. Absence of this enzyme → injury to retinal cells.

C)- Visual acuity :-

* Def.:- is the ability to discriminate between two separate stimuli in space (it's a measure to accuracy of vision).

*** Minimum discriminable (aligning power of the eye):-**

- is the ability to determine relative location of two visible lines in relation to each other.
- Example :- break in contour.
 - two lines one above & the other is below & to one side with a threshold angle inbetween as small as 3 sec. of an arc.
- this corresponds to geometrical retinal images falling on foveal cones only.

*** Minimum visible :-**

- is the ability to determine the smallest object in space with threshold angle as small as 0.5 - 1 sec. of an arc.
- Example :- detection of thinnest black line (e.g. thin telegraph wire) against clear sky.

*** Minimum resolvable :-**

- is the ability to determine 2 separated points with threshold angle as small as 60 sec. of an arc, this angle is subtended by a single cone, this needs :-
 - a)- forced fixation.
 - b)- focused image.
 - c)- photopic illumination.
 - d)- integrity of visual system.

*** Factors affecting visual acuity :-**

I)- Stimulus factors :-

a)- intensity of illumination (L):-

- $\uparrow$ illumination $\rightarrow \uparrow$ VA (suitable illumination is 20 feet candel).
- $\uparrow\uparrow\uparrow$ illumination $\rightarrow \downarrow$ VA.

b)- background :-

- $\uparrow$ contrast $\rightarrow \uparrow$ VA (suitable contrast is white-black).

c)- shape of the test :-

- parallel white & black lines i.e. grating with gap inbetween measure minimum angle of resolution.

d)- distance of the test from the eye :-

- near $\rightarrow \uparrow$ size of the image.
- far $\rightarrow \downarrow$ size of image, but angle of vision is constant.

e)- accommodation :-

- good accommodation $\rightarrow$ better image.

f)- time of exposure (duration = D):-

- $\downarrow$ time $\rightarrow \downarrow$ VA.
- this's compensated by illumination ($D \times L = \text{constant}$).

g)- interaction effect :-

- isolated symbols are better than adjacent symbols because the contour interaction of adjacent symbols in each row $\rightarrow \downarrow$ VA (this is called crowding phenomena).

h)- colour :-

- white $\rightarrow$ better.
- blue $\rightarrow$ worst.

II)- Receptor factors :-a)- refractive errors :-

- defocusing, overcome it by miosis, pinhole & accommodation.

b)- pupil size :-

- mydriasis $\rightarrow \uparrow$ pupil size $\rightarrow \uparrow$ VA.
- pupil size > 6 mm $\rightarrow \uparrow$ illumination $\rightarrow \uparrow$ aberration & internal reflection at retinal cones $\rightarrow \downarrow$ VA $\rightarrow$ Stiles Crawford effect (optimum pupil size is 3 mm).

c)- region of the retina :-

- in light adaptation $\rightarrow$ maximum acuity is at the fovea due to neural connection of foveal cones with private lines to visual cortex.
- in dark adaptation $\rightarrow$ maximum acuity is 30° from the center of the fovea.

d)- binocular vision :-

- better than unocular vision.

e)- development of visual system.

f)- old age :-

- ↓ VA due to hypoxia, fatigue & changes occurring in the visual pathway & in eye.

g)- meridional variation :-

- oblique illumination is bad while axial (horizontal & vertical) illumination is better.

h)- eye movement :-

- continuous fine eye movements are important for constant stimulation of cones → maintain image perception & fixation.

*** Contrast sensitivity :-**

- seeing involves not only detection of fine high-contrast detail (as measured in conventional tests of VA), but also the ability to detect coarser features of low contrast such as large objects seen through a fog, or through edematous cornea or cataract.

- Measurement of contrast sensitivity :-

- a)- sinusoidal grating :-* i.e. parallel, equal width bright & dark bars in which brightness changes in a sine wave manner are used.
 - b)- spatial frequency of grating :-* is a number of cycles one bright plus one dark bar per degree of visual angle, 30 cycles/degree is = $6/6$ & 5 cycles/degree = $6/36$.
 - c)-* contrast between maximum & minimum brightness is also varied, the least contrast required for a grating of a given frequency to be seen is determined.
 - d)-* for most objects, contrast sensitivity is greater for 5 cycles/degree, less for higher or lower frequencies. Fine detail (high frequency will be seen only when the contrast is high).
- the highest frequency detected when contrast is 100% (B & W) corresponds to VA as usually increased.
 - reduced contrast sensitivity was found in :- D.S, diabetic maculopathy, OAG & in patients with normal Snellen's acuity & inspite of this feel that their vision is impaired.

D)- Adaptation :-

- def.:- is the ability of the visual system to adjust itself to different levels of illumination.

* Mechanisms :-

I)- Pupillary light reflex :-

- regulates amount of light entering the eye.
- it's rapid (one sec.) but of limited value.

II)- Photochemical adaptation :-

- it's slow (few minutes):-
 - a)- *dark adaptation* :- in which reformation of rhodopsin $\rightarrow$ $\uparrow$ retinal sensitivity to light.
 - b)- *light adaptation* :- in which bleaching of rhodopsin & iodopsin $\rightarrow$ $\downarrow$ sensitivity to light.

III)- Neural adaptation :-

- very rapid, all or none rule, depending on minimum threshold of impulses.
 - a)- *central* :- exposure of one eye to light $\rightarrow$ $\downarrow$ sensitivity to light.
 - b)- *retinal* :- stimulation of one area of the retina $\rightarrow$ inhibition of surrounding areas (lateral inhibition).

* Light adaptation (Photopic vision):-

- Mechanism :- light $\rightarrow$ most visual purples converted by bleaching into retinal vit.A & opsin $\rightarrow$ $\downarrow$ visual purples (pigments) $\rightarrow$ $\downarrow$ sensitivity of the eye to light.

- Characters :-

- a)- $\downarrow$ retinal sensitivity to light (objects must be illuminated brightly to see their details.
- b)- $\uparrow$ VA.
- c)- possible colour vision.

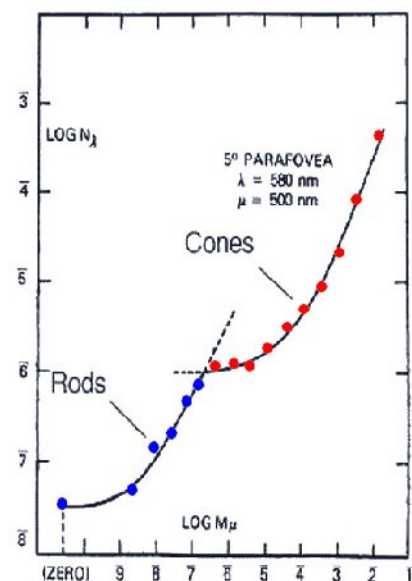


Figure 11. Light adaptation curve plotted as increment threshold versus background luminance (or a threshold-versus-intensity; t_i curve). The above plot shows increment threshold (N_t) and background luminance (M_μ). Light of two different wavelengths are used in this case (580 nm for the test and 500 nm for the background). Stiles' data from Davson (Davson's Physiology of the Eye, 5th ed. London).

- Phases :-

a)- α - phase :-

- rapid 0.2 sec. due to neural inhibition.
- correspond to a-wave in ERG.

b)- β - phase :-

- slow 1 min. due to photochemical decomposition (related to adaptation of optic nerve to continuous stimuli).

* Dark adaptation (Scotopic vision):-

- Mechanisms :- dark $\rightarrow$ most of vit.A is converted into rhodopsin $\rightarrow$ $\uparrow$ visual purples (pigments) $\rightarrow$ $\uparrow$ sensitivity of the eye to light.

- Characters :-

a)- $\uparrow$ retinal sensitivity to light :-

- objects can be seen in extremely low illumination but object details cannot be detected.

b)- $\downarrow$ VA (cones are not functioning) $\rightarrow$ so best vision is paracentral.

c)- impossible colour vision (cones are not functioning).

d)- central scotoma 2.5° :-

- corresponds to non-functioning macular cones.

e)- nocturnal myopia (1 - 15 D) due to :-

- spherical aberration due to mydriasis.
- chromatic aberration due to shift of eye sensitivity to blue-green (short wave lengths).

f)- nocturnal presbyopia :-

- due to flattening of the lens (weak accommodation).

g)- autokinetic shift :-

- when looking to a small spot of light in case of dark adaptation it appears moving.

h)- Purkinje phenomena (shift):-

- shift of retinal sensitivity to short wave lengths of light.
- maximum sensitivity is for wave lengths around 500 nm i.e green-blue which appear brightest.
- equalization of colours is the manifest sign of Purkinje shift due to non-functioning cones.
- $\uparrow$ retinal sensitivity.

- Measurement (dark adaptation curve):-

- a)- measured by adaptometer which measures the minimum light threshold (weakest flash of light visible to the person in dark adapted state but before that dark adaptation we expose the person to a bright glaring light).
- b)- we measure the minimum threshold against time in minutes (light intensity in milli Lambert).
 - glaring of the eyes by white bright light for about 5 min. to achieve stimulation of all pigments & bleaching of all.
 - make the room completely dark.
 - give intermittent weak light stimuli of known intensity & when patient sees, the examiner put a point on the sheet against time taken to receive this stimulus.
 - ↓ intensity of light stimuli gradually till just seen by the patient while the examiner putting points on the sheet against time till passage of 30 min. (time of minimal response after which response is stationary).
 - parts of the curve :-
 - 1)- photopic (cone segment or adaptation of cones):-
 - cause :- rapid synthesis of iodopsin.
 - maximal adaptation is 5 - 10 minutes.
 - 2)- scotopic (rod segment or adaptation of rods):-
 - cause :- slow synthesis of rhodopsin.
 - maximal adaptation is 30 min.

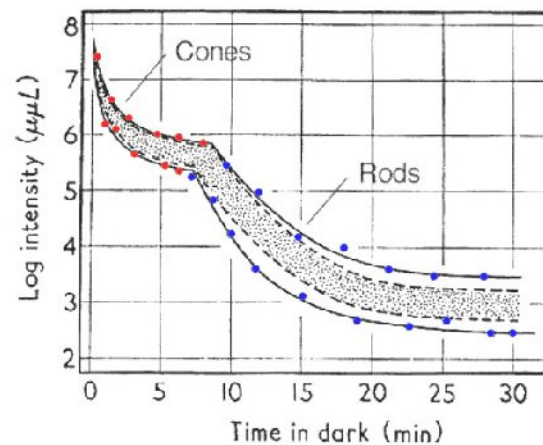
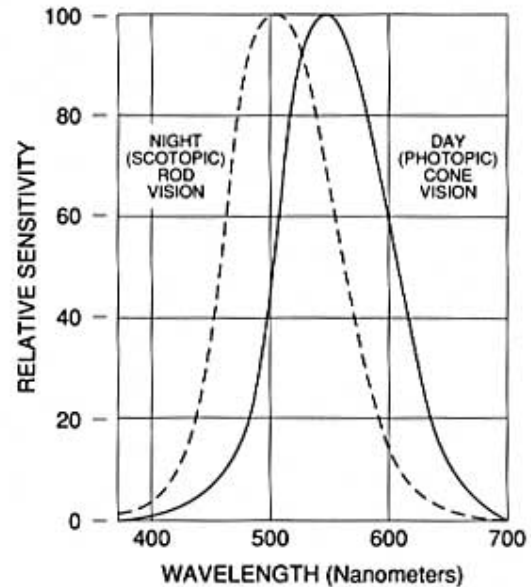


Figure 1. Dark adaptation curve. The shaded area represents 80% of the group of subjects. Hecht and Mandelbaum's data from From Pirenne M. H. Dark Adaptation and Night Vision. Chapter 5. In: Davson, H. (ed), The Eye, vol 2. London, Academic Press, 1962.

- rods are more sensitive to light than cones.
- each 100 rods converge to a single ganglion cell (spatial summation).
- minimal threshold :- minimal intensity is 2.5 milli Lambert.

- Factors affecting dark adaptation :-

I)- Receptor factor :-

a)- pupil size :-

- optimal size is 6 mm.
- if < 6 mm $\rightarrow$ $\uparrow$ minimal threshold.

b)- region of the retina stimulated :-

- fovea $\rightarrow$ only cones (monophasic curve).
- extrafoveal $\rightarrow$ rods & cones (biphasic).
- so foveal stimulation is responsible for cone segment & extrafoveal stimulation is responsible for rod segment.

c)- old age :-

- $\uparrow$ minimal threshold due to anoxia & fatigue plus changes in visual pathway & eyes.

II)- Stimulus factors :-

a)- Pre-adapted glaring light (intensity, duration & colour):-

- intensity :- $\uparrow$ intensity $\rightarrow$ $\uparrow$ time needed for dark adaptation (slow) & vice versa.
- duration :- $\uparrow$ duration $\rightarrow$ $\uparrow$ time needed for dark adaptation (slow).
- colour :- red (rods are not sensitive to red so no bleaching of rhodopsin occurs) $\rightarrow$ rapid dark adaptation.

b)- Light stimulus during dark adaptation :-

- wave length :- short wave length $\rightarrow$ small or weak threshold i.e. $\downarrow$ minimal threshold, but long wave lengths $\rightarrow$ $\uparrow$ minimal threshold.
- duration :- if < 1 sec. $\rightarrow$ temporal summation.
- size :- $\uparrow$ size of the stimulus act as a strong stimulus.

* Adaptation disorders :-

	NECTALOPIA	HEMERALOPIA
- def.	- night blindness due to impaired rod function & impaired dark adaptation.	- day blindness due to impaired cone function & impaired light adaptation.
- causes	a)- congenital. b)- retinitis pigmentosa. c)- vit.A ↓. d)- major tranquilizers.	a)- congenital :- - monochromatism as a part of retinitis pigmentosa. - hereditary cone dystrophy. b)- acquired :- - macular toxicity. - glaucoma (destruct cones 1 st).
- clinical picture	- night blindness. - peripheral field defect. - normal VA. - good colour vision.	- bad day vision. - better night vision. - central scotoma. - ↓ peripheral vision. - ↓ VA. - colour blindness.

E)- Light sense :-

* Factors affecting minimal light threshold :-

(minimal stimulus can be seen by the person or minimal visible)

I)- Stimulus (extrensic) factors :-

a)- size of the stimulus :-

- size & luminance of stimulus compensates each other within limits (size x luminance = constant).
- this's applied more at retinal periphery (why ?):-
1)- rod system can do spatial summation i.e. 2 simultaneous

subthreshold stimuli on 2 groups of rods can summate through horizontal cells & stimulate one ganglion cell.

- 2)- rod system can do temporal summation i.e. 2 successive sub-threshold stimuli can summate through an amacrine cells & stimulate one ganglion cell.

N.B. No summation in cone system.

b)- duration of the stimulus :-

- if < 1 sec. $\rightarrow$ the stimulus will not be seen.
- $\downarrow$ intensity of stimulus can be compensated by $\uparrow$ duration (temporal summation will occur).
- if < 30 sec. $\rightarrow \downarrow$ intensity compensated by $\uparrow$ duration.
- if 30 millisecon. - 1 sec. $\rightarrow \downarrow$ intensity not compensated as no spatial summation (partial summation).

c)- colour (wave length) of the stimulus :-

- long wave length $\rightarrow \uparrow$ minimal light threshold.

d)- mode of light presentation :-

- continuous or intermittent (affect sensibility).

II)- Receptor (intrinsic) factors :-

a)- size of the pupil (in photopic vision):-

- peripheral light rays at pupil margin are less effective than axial rays at the center of the pupil, so large pupils are less effective because peripheral rays pass obliquely to retinal cones $\rightarrow$ internal reflection & these oblique rays are less effective on visual purples, although central rays fall perpendicular to cones $\rightarrow$ more effective, this's called Stiles Crawford effect.

b)- region of the retina stimulated :-

- fovea with cones is concerned with colour vision & VA ($\uparrow$ minimal threshold $\rightarrow$ photopic receptors).
- as we go peripherally, rods $\uparrow \rightarrow$ detection of very short wave lengths or very weak light ($\downarrow$ minimal threshold $\rightarrow$ scotopic receptors).

c)- adaptation :-

- dark adaptation $\rightarrow \downarrow \downarrow \downarrow$ minimal light threshold as small as 2.5 milli Lambert because retinal sensitivity $\uparrow$.

d)- age :-

- fatigue, hypoxia & attention affect minimal light threshold.

*** Sensory response to a single stimulus :-**

- the stimulus (light) to be effective should lie in spectrum between 400 - 700 nm.
- the intensity should be suitable, because as intensity $\uparrow \rightarrow$ light sense $\uparrow$ till reaching 10^9 times minimal light threshold at which dazzling occurs.
- stages of light sense on exposure to a single flash of light of moderate intensity & short duration :-

I)- Latent period (0.1 sec.):-

- correspond to time needed for bleaching of visual purples & transmission of nerve impulses to the brain.
- no light sense.
- duration of the latent period varies according to stimulus intensity as latent period $\downarrow$ with $\uparrow$ intensity shown by pendulum of Pulfrich, clear glass on one eye & dark glass on the other eye $\rightarrow$ pendulum appear to move ellipse perpendicular to plane of oscillation due to eye with clear glass receive stimulus faster than eye with dark glass.
- latent period is longer in periphery as fixation reflex time is added.

II)- Primary image :-

- rapid $\uparrow$ sensation followed by $\downarrow$ sensation to average level.
- $\uparrow$ intensity $\rightarrow \uparrow$ sensation of light & $\downarrow$ latent period (Broca - Sulzer effect).

III)- Adaptation :-

- as the stimulus continues, the sensation $\downarrow$ slowly due to adaptation.

IV)- Persistence of sensation (0.15 sec.):-

- when the adapted state is interrupted by stoppage of light stimulus, there will be a period of light sense after stoppage of stimulus because some nerve impulses still in its way to the brain.
- persistence is explained by the fusion of successive stimuli, it's longer with blue > red & it's different from after images).

* Sensory response to intermittent stimuli :-

- intermittent slow (every sec.) light stimulus is seen as alternating light & dark.
- if the frequency is $\uparrow$ to 15 times/sec. $\rightarrow$ light stimulus is seen as continuous light fluctuating in intensity, this is called flicker.
- if the frequency is $\uparrow$ more upto 40 times/sec. $\rightarrow$ the light stimulus is seen as continuous light with no fluctuation i.e. critical fusion frequency is reached.
- this fusion is caused by persistence of light sensation after cessation of the stimulus & occur on level of ganglion cells & brain.

* Critical Fusion Frequency (CFF):-

- def.:- it's a transition point from flickering to fusion (continuous light without fluctuation in intensity) occurs when light fluctuate in intensity in a frequency of = 40 times/sec. (or it's the rate of light stimuli by sec. to be seen by the person as a continuous light without flickering).
- this's due to persistence of light sensation after cessation of the stimulus.
- occurs at the level of the ganglion cells of the retina & brain.
- Factors affecting CFF :-

I)- Stimulus (extrinsic) factors :-

a)- intensity :-

- CFF is proportional to log. of average luminance (intensity), this is called Ferry-Porter law.
- this is applied only for low intensity (0.1-400 candel/m²).
- at top of the curve (α -point) where there is transition between photopic & scotopic vision, CFF is 10 in photopic vision & 1 in scotopic vision

_____ = ____.

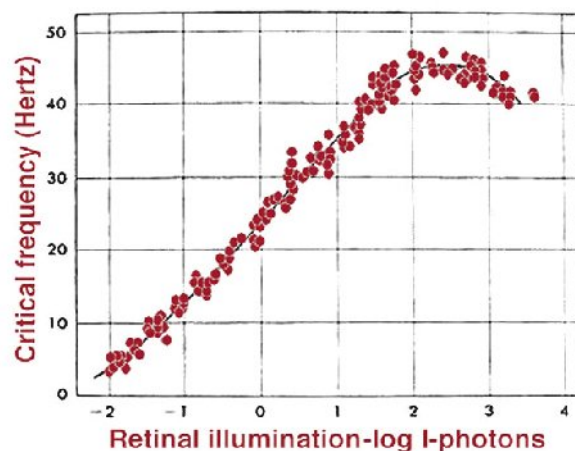


Fig. 7. CFF at the fovea over a range of retinal illuminance (photons = trolands) of the test field, showing conformity of the Ferry-Porter Law over four logarithmic units. Hedri and Verrijp's data from Hart Jr, W. M., The temporal responsiveness of vision. In: Moses, R. A. and Hart, W. M. (ed) Adler's Physiology of the eye, Clinical Application. St. Louis: The C. V. Mosby Company. 1987.

b)- size of the stimulus :-

- CFF is proportional to size of the stimulus.

c)- wave length (colour of the stimulus):-

- only with weak stimuli (0.1 - 400 candel/m²), CFF is low with red (long wave length) than blue (short wave length).

d)- light/dark duration ratio :-

- CFF is maximum with equal duration.

II)- Receptor (intrinsic) factors :-

a)- region of the retina

stimulated :-

- CFF behaves as VA, i.e. CFF is highest at fovea, ↓ at central 5° & ↓↓↓ as we go peripherally.

b)- adaptation :-

- ↑ adaptation → ↑ CFF (retina is adapted to test luminance).

c)- pupillary size :-

- ↑ pupillary size → ↑ CFF, due to ↑ retinal illumination by mydriasis (but within limits).

d)- binocular vision :-

- CFF is ↑ with binocular vision.

e)- anoxia, age & alcoholic

intoxication :-

- ↑ CO₂ → ↓ CFF.

- Value of CFF :-

- a)- test retinal function.

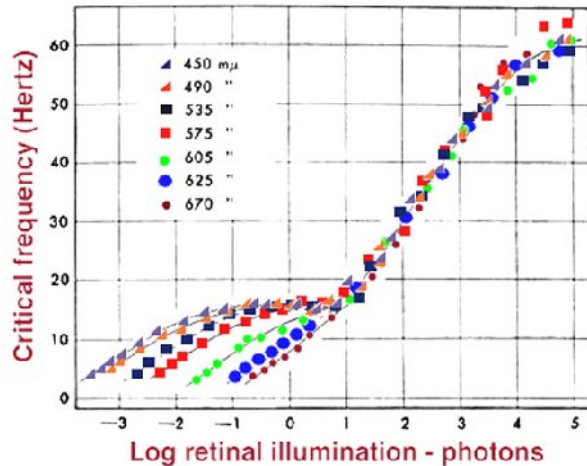


Fig. 8. CFF of 19 degree test field over a range of retinal illuminance (photon = troland) for different monochromatic lights of different wavelengths. Hecht and Shlaer's data from Hart Jr, W. M., The temporal responsiveness of vision. in: Moses, R. A. and Hart, W. M. (ed) Adler's Physiology of the eye, Clinical Application. St. Louis: The C. V. Mosby Company, 1987.

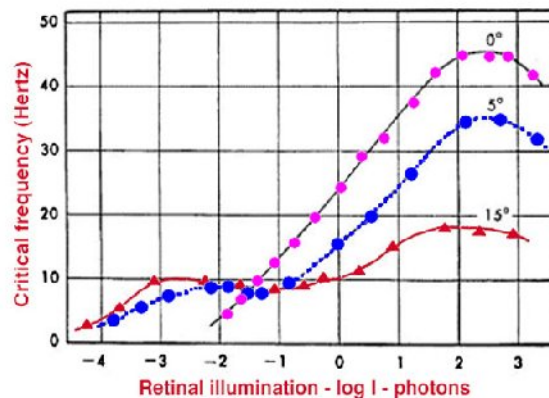


Fig. 9. CFF of a 2° white test field over a range of retinal illuminances (photons = troland) measured at the fovea, 5° above the fovea and 15° above the fovea. Hecht and Verrijp's data from Hart Jr, W. M., The temporal responsiveness of vision. in: Moses, R. A. and Hart, W. M. (ed) Adler's Physiology of the eye, Clinical Application. St. Louis: The C. V. Mosby Company, 1987.

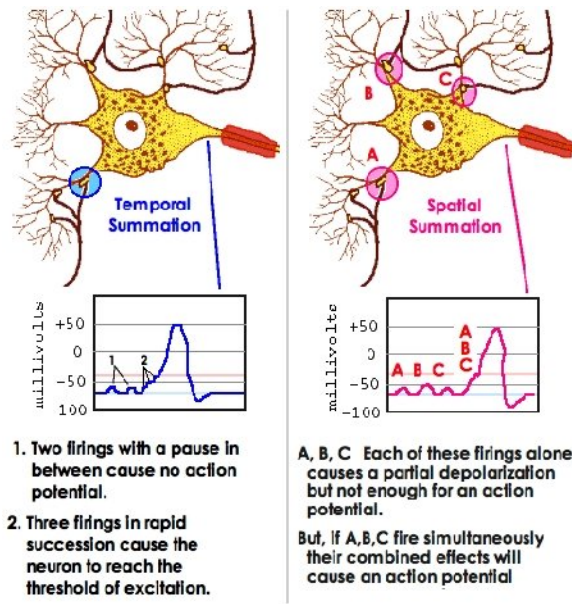
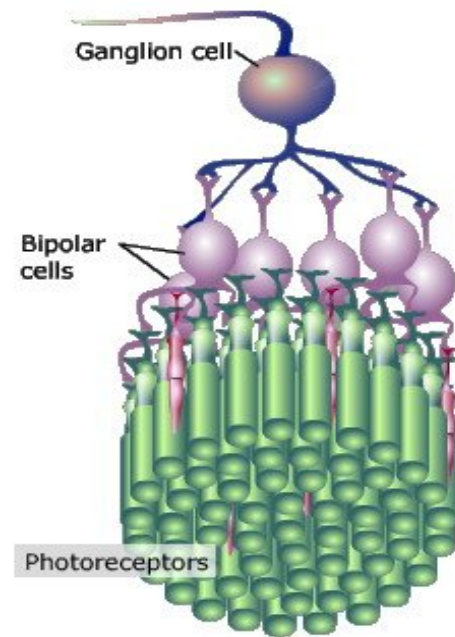
- b)- principle of TV & cinema, as we darken the room to ↓ CFF (↓ in scotopic vision) as the speed of image in dark is double that in light.
- if speed of image > 24 view/sec. → fast image movement.
 - if speed of image < 24 view/sec. → slow image movement.

* Form sense :-

- the form sensation is affected by :- temporal summation & spatial summation.

I)- Spatial summation (interaction):-

- many rods converge to one bipolar cell then connected to horizontal cells & bipolar cells are connected to single ganglion cell.
- the spatial summation can lead to either activation (facilitation) or inhibition :-
 - a)- *Activation :-*
 - photoreceptors help each other as occur in rods in peripheral retina on exposure to subthreshold stimuli.
 - b)- *Inhibition :-*
 - photoreceptors inhibit each other as occur in cones in central retina when there's glare during excess light.
- this interaction modifies the retinal sensitivity & hence modifies the level of minimal threshold.



II)- Temporal summation :-

- 2 successive subthreshold stimuli are summated by a group of rods to one ganglion cell through amacrine cells.
- the effect of the stimulus is continuous after cessation of stimulation.
- Three phenomena must be differentiated :-

a)- Persistence of sensation :-

- is one stage of stages of response to a single light stimulus (flash of light) due to some nerve impulses are still in their way to the brain.
- occur at the level of ganglion cells & brain.

b)- Positive after image of Hering :-

- occurs after disappearance of the primary image with no further stimulus when the person either close his eyes or looking at a black surface, *what happen ?* a 2nd similar image but fainter sensation appear if the stimulus was very intense, then a 3rd +ve image appears after a dark interval & there's oscillation of the sensation.

c)- Negative after image :-

- occurs after disappearance of the primary image with no further stimulus when the person look at a bright white surface (act as a stimulus), *what happens ?* same area of the retina is stimulated & the sensation to similar stimuli is ↓ :-
- 1)- if the stimulus was white → after image will appear darker.
- 2)- if the stimulus was coloured → after image will be of the complementary colour.
- 3)- if the stimulus was very intense & of long duration → after image will be pronounced.
- i.e. stimulation has a stimulating effect on succeeding different stimuli & inhibitory effect on succeeding similar stimuli.
- nature of after image is photochemical but its duration is cortical :-
- 1)- +ve after image :- is due to retinal after discharge.
- 2)- -ve after image :- is due to local ↓ in retinal sensitivity.

*** After image :-**

- *def.* :- they are visual sensations that are perceived after cessation of visual stimulation.
- *types* :- +ve & -ve after images (*see before*).
- *applied physiology* :-

*** Cupper's method (-ve after image) in ttt of eccentric fixation :-**

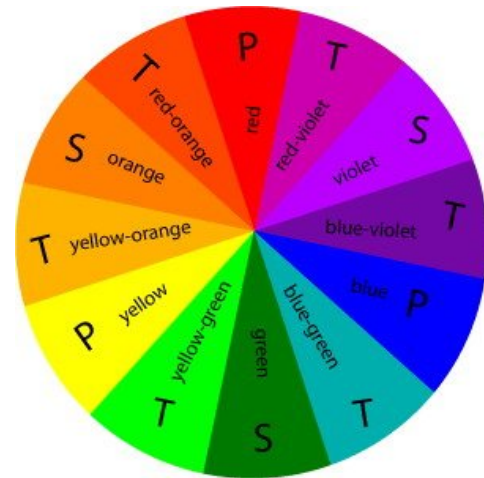
- patient cannot fixate an object in space by the fovea with the aid of euthyscope (modified ophthalmoscope) which can project white light on the posterior pole of the retina in the form of disc with dark central spot of 3° - 5° , this spot cover & protect the macula.
- the retina (except the macula) is dazzled for 10 - 30 sec. when the eyes look at a light screen, the patient will see a -ve after image (a clear central disc surrounded by a dark ring).
- the aim of this ttt is to prolong the period of appearance of this after image, so that the patient is trained to recognize the position of his fovea in space.

F)- Colour vision :-

*** Important definitions :-**

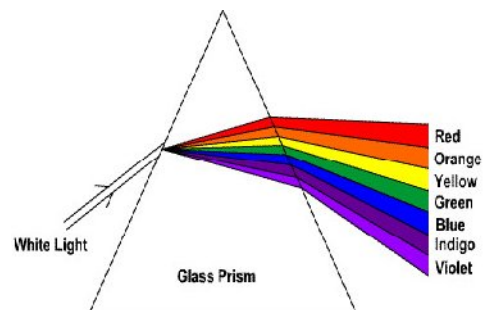
- *Luminosity* :- subjective sensation of illumination.
- *Luminance* = candelas/unit area.
- *Brightness* :- means $\uparrow$ or $\downarrow$ luminance.
- *Hue* :- subjective assessment of colours.
- *Tints* :- colour mixed with white.
- *Shades* :- colour mixed with black.
- *Purity* :- degree of freedom from mixtures with light of other wave lengths.
- *Saturation* :- contain multiple wave lengths of the same wave length i.e. of the same colour.

- **Complementary colours** :- they are 2 colours when introduced together & equally stimulated produce white light, one colour is from one extreme of spectrum & the other colour is from the other extreme of spectrum e.g. yellow-blue, orange-violet, red-green blue & green-blue red (purple).



* Wave lengths of visible spectrum :-

- *violet* :- 380 - 430 nm.
- *blue* :- 430 - 460 nm.
- *blue-green* :- 460 - 500 nm.
- *green* :- 500 - 570 nm.
- *yellow* :- 570 - 600 nm.
- *orange* :- 600 - 630 nm.
- *red* :- 630 - 700 nm.



* Factors affecting colour vision :-

I)- Stimulus factors :-

a)- amount of illumination :-

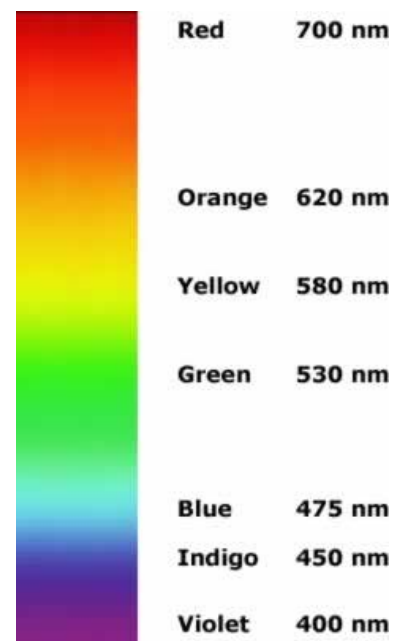
- at high intensity → all hues tend to be yellowish white.
- at high intensity → hue discrimination is
- best colour perception is at medium intensity & high saturation.

b)- saturation :-

- monochromatic light may be altered as it becomes unsaturated e.g. red → pink & orange → yellow.

c)- hue :-

- is dependent on the area of the retina stimulated.



d)- nature of the surface :-

- absorb certain wave lengths & reflect the specific wave length of certain colour e.g. white → reflection of all wave lengths, black → absorption of all wave lengths.

e)- brightness (Bezold - Brucke hue shift):-

- at different levels of illumination, same wave length gives different colours.

f)- duration of stimulation :-

- short better than long wave lengths.

II)- Receptor factors :-a)- pupil size (Stiles - Crawford effect):-

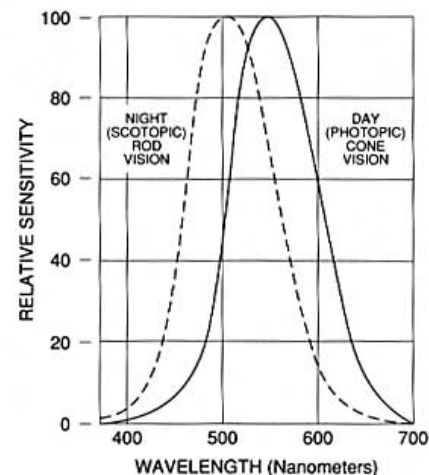
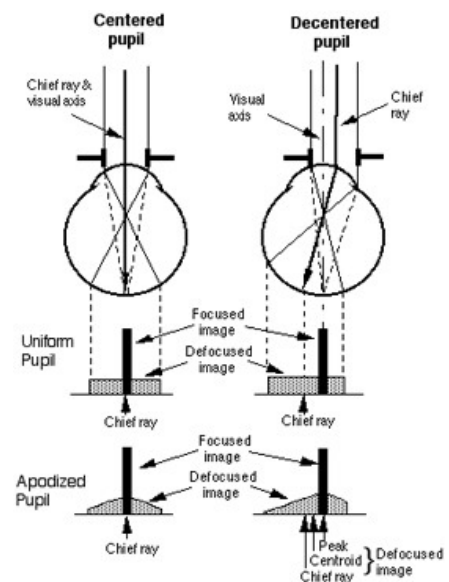
- peripheral rays pass obliquely to retinal cones → internal reflection & these oblique rays are less effective on visual purples although central rays fall $\perp$ to cones → more effective.

b)- Purkinje shift :-

- is a shift in sensitivity of the eye during dark adaptation associated with $\downarrow$ cone function & is manifested by equalization of colours.
- hue discrimination disappears but luminosity discrimination remains, or when the eye compare light of different wave lengths but of equal luminance → yellow-green (500 - 600 nm) appears brightest under photopic conditions, while green (540 nm) appears brightest under scotopic conditions.

c)- chromatic aberration :-

- shorter wave lengths are more refracted by the lens > longer wave lengths.
- human eye is emmetropic for yellow (580 nm).



- blue is refracted in front of the retina (myope).
- red is refracted behind the retina (hypermetrope).

d)- macular pigments :-

- there's a yellow spot in the center of the macula upto 5° from the fovea due to presence of xanthophil pigment which absorb blue radial light > blue tangential light.

e)- crystalline lens :-

- absorb short wave lengths upto 450 nm in young & lens is transparent.
- absorb wave lengths upto 540 nm in old age & lens is yellow.

f)- fatigue & -ve after image.

* Mechanisms (theories) of colour vision :-

I)- Trichromatic theory of Young Helmholtz :-

- there are 3 types of cones in the retina containing 3 types of photochromatic pigments & each of them respond maximally to certain colour of certain wave length (blue - green - red) → primar colours.

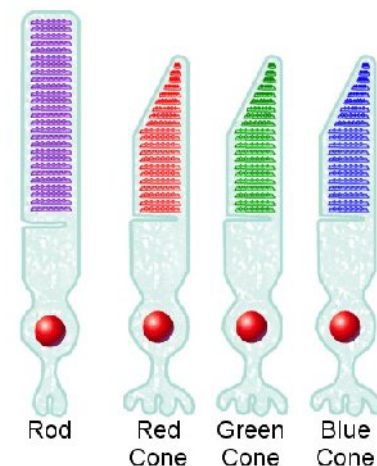
N.B. cones responsible only for colour vision, while rods have no role.

- evidences :-

a)- mixing the 3 main colours produce all colours in nature.

b)- electrophysiological studies of Granit :-

- he put a microelectrode on cone & another electrode on optic nerve → generation of potential at level of ganglion cells.
- he found that there are 2 types of ganglion cells :-
 - 1)- dominator photopic :- not for colour, but for white.
 - 2)- modulator type :- for 3 colours.
- this opinion corresponds to a theory says that there are 3 types of cones of different 3 photochemicals called 3 modulator cones & there is one dominator type of cones for white & equal stimulation of the 4 types of cones → 3 chromatic cones inhibit each other & the net result will be sensation of white, but unequal stimulation of the 4



types → activation of one specific ganglion cell & specific colour sensation result.

c)- colour blindness is explained by this theory :-

- trichromats :- partial defect in one type.
- dichromats :- total absence of one type.
- monochromats :- absence of 2 types.

d)- -ve coloured after image :-

- when we look to a green object for long time then shift to a bright white surface → fatigue of green cones with no further response to green, so that white surface will appear purple (bluish red) due to predominance of unfatigued red & blue receptors.

e)- binocular cortical fusion of colours :-

- one can fuse red from one eye with green from the other eye to produce yellow.
- this fusion occurs in the cortex not in the retina.
- Worth 4 dots test can be explained by this theory.
- this's against Hering's theory which postulates a yellow receptor in addition to the 3 others.

f)- lateral geniculate body :-

- has 6 layers (neuro-anatomical arrangement), 3 layers received from each eye.

g)- photography, TV & colour printing :-

- based on this theory.

h)- Bezold - Brucke hue shift :-

- when light of special hue (wave length) ↑ in intensity → it gives sensation of another colour or hue or wave length (hue shift) i.e. this is explained by that a given intensity of a given wave length stimulates a particular type of cones, when intensity ↑ → stimulation of other cones → give sensation of another hue (wave length).

- objections :-

- a)- VA is not affected by different light colours i.e. VA with red light (stimulation of some cones) is not < VA with white light (stimulation of all cones).
- b)- psychologists consider white & yellow as distinct colours & not as

composites of 3 main colours.

c)- anatomically, no 3 separate cones.

II)- Hering opponent colour theory :-

- transmission of colour message along the visual pathway.
- the photoreceptors (cones) only detect light but the discrimination starts beyond the retina with coding mechanisms of visual pathway.
- so we identify 4 colours (red, green, blue & yellow) & not only 3 colours.
N.B. this theory accept trichromatic theory.
- there are 3 systems of transmission functioning in pairs :- black - white, red - green & blue - yellow.
- the colour of one system opposes the other & never mix.
- when a red signal is sent to brain, a green can't be sent simultaneously.
- coloured coded cells in the nervous system :-

a)- colour coded cells in anterior visual pathway (LGB):-

- two types of cells are found :-

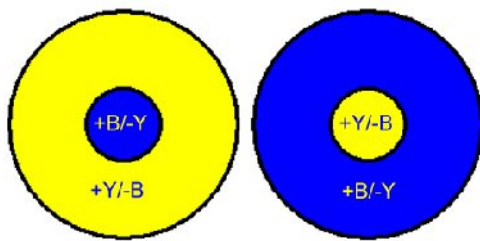
1)- opponent colour cells :-

- these cells have different response for different portions of visible spectrum :- ↑ response by yellow, ↓ by blue & no response by white.
- divided into two large groups :-
 - * blue - yellow opponent cells :- detect level of stimulation of blue cones.
 - * red - green opponent cells :- detect level of stimulation of red - green cones.

N.B. it's believed that there are cells sum input of red - green cones to produce yellow signal.

2)- double opponent colour cells :-

- these cells have center & surround, both are coded e.g. the center is stimulated by red & inhibited by green while the the surround has the opposite.
- uniform stimulation of center & surround → no response (white light).



Double Opponent cells detect spectral contrast

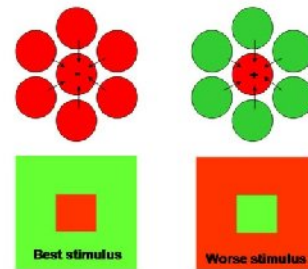


Fig. 25 shows how concentrically organized double opponent cells can be constructed by having identical (red) neighboring cells inhibit a central cell (red) and have opposite.

b)- coded cells in the cerebral cortex (blobs):-

- site → in primary visual cortex (area 17) layers 2, 3, 5 & 6.
- distribution → concentrated in layers 2 & 3.
→ less concentrated in 5 & 6.
- functions → colour differentiation.
→ double opponent cells in layers 2 & 3.
→ opponent cells in layers 5 & 6.
- colour vision is trichromatic at retinal level but transmitted in the visual pathway in opponent colour signals, discrimination occurs in coded cells for 4 colours : red, green, blue & yellow.

* Colour blindness :-

- def.:- loss of colour discrimination either partial (common) or complete (rare).
- the most common is difficult differentiation between red & green.
- in addition, there are major changes in the luminosity curves so that the relative brightness of coloured surfaces is changed.

I)- Normal trichromacy (normal colour vision):-

- 92% of population see & differentiate all colours & pass all tests of colour vision.
- they have :- all 3 types of cones.
 - normal concentration of cone pigments.
 - normal retinal wiring (transmission).

II)- Colour blindness (8% of population):-

a)- anomalous trichromacy (colour weakness):-

- 75% of colour blindness (6% of population).
- recognize all colours but need a higher threshold for certain colours than normal & need long time for colour discrimination.
- types (depends on which cone pigment is subnormal):-
 - 1)- *deutranomaly* :- weak green.
 - 2)- *protanomaly* :- weak red.
 - 3)- *tritanomaly* :- weak blue.

b)- dichromatic vision :-

- 25% of colour blindness.
- recognize 2 colours only instead of 3 colours.
- types (depends on which cone pigment is abnormal):-
 - 1)- *deutanopia* :- green blind.
 - 2)- *protanopia* :- red blind (red is confused as green).
 - 3)- *tritanopia* :- blue blind.

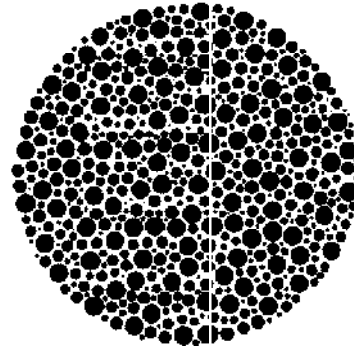
c)- monochromatism :-

- all wave lengths of spectrum have a grey colour i.e. complete failure of colour discrimination.
- types :-
 - 1)- *rod monochromatism* :-
 - 1/30,000 of population.
 - cones are pathologically abnormal.
 - complete colour blindness.
 - ↓ VA.
 - nystagmus.
 - macular dystrophy.
 - no Purkinje phenomena.
 - 2)- *cone monochromatism* :-
 - 1/100 million of population.
 - the cause is central (central defective mechanism).
 - the 3 types of cones are present.
 - normal or ↓ VA.
 - nystagmus.
 - complete colour blindness.

- tests of colour blindness :-

I)- Ishihara test :-

- plate filled with coloured dots among them there's a letter or figure of different colour is present.



II)- Colour matching :-

- coloured beads & ask the patient to catch certain colour which is similar to a given sample.

III)- Spectroscopic test :-

- matching of isolated spectral colour with other spectral colours most accurate.

IV)- Coloured light from aperture changed by coloured glass + filter to stimulate fog or moist & ask the patient to recognize the colour.

G)- Macular Function Tests :-

I)- Visual acuity :-

- elevation of sensory retina e.g. CSR → hypermetropia.
- cone dysfunction → ↓ VA.

II)- Pupillary reflexes :-

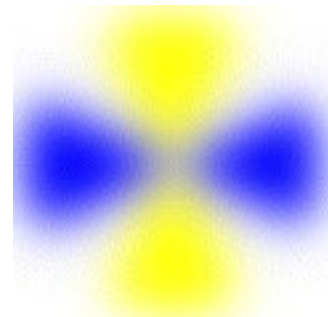
- normal in macular disorders but affected in mild optic nerve lesions.

III)- Colour vision :-

- not markedly affected in macular lesion but early affected in optic nerve lesion.

IV)- Haidinger's brushes :-

- observing a surface illuminated by a plane polarized white light → seeing of yellow-blue brushes



- radiating from fixation point due to variation in light absorption by macular pigments oriented at foveal region (xanthophyl pigment).
- disturbed orientation of macular pigments as in macular edema → disappearance of brushes very early.

V)- Amsler grid :-

- 10 cm² deviated into 5 cm² each of them subtend an angle of 1" when seen at a distance of 33 cm from the eye.
- patient wear his correcting glasses & cover one eye & look at the Amsler grid at a central dot with the uncovered eye.
- any distortion, wavy lines or blurring → means macular dysfunction.

VI)- Photostress test :-

- patient fixate light of pin torch at 30 cm away from the eye for 10 sec.
- recovery time is determined when best corrected visual acuity is returned on reading 3 letters of test card (normally 50 sec.).
- perform the test in the other eye.
- if > 50 sec. → macular lesion e.g. CME or CSR.
- this test is normal in optic nerve lesion.

VII)- Purkinje vascular entoptic test :-

- gently rubbing the lid by a pin torch light → if macula is healthy, the patient will describe his vascular marking as brushes.

VIII)- Visual field :-

- central scotoma in foveal lesions.

IX)- ERG :-

- ewcord bulk electrical response of the retina on exposure to light.

X)- VEP :-

- recording of electrical of visual cortex by stimulation of retina as the macula representation is about 1000 that of the retina.
- macula represented area lie superficially in the occipital lobe while peripheral retina lies deeper.

XI)- Flickering.

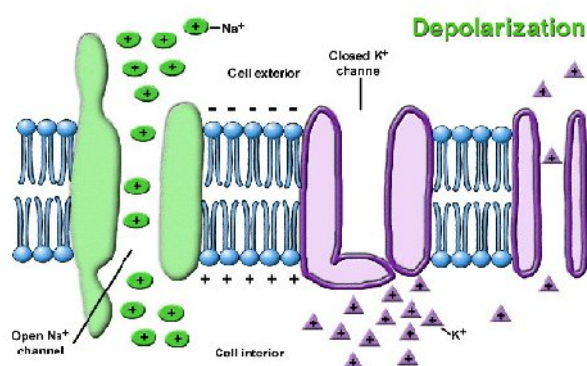
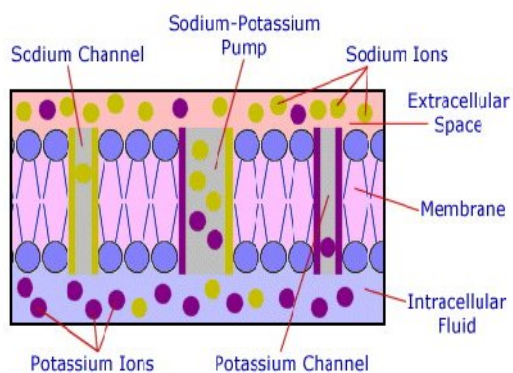
XII)- two light discrimination test :-

- at distance 60 cm.
- 2 light pin torch adherent are separated gradually till the patient see 2 light separated :-
 - a)- VA > 3/60 see 2 light 5 cm apart.
 - b)- VA CF - 3/60 see 2 light 7 cm apart.
 - c)- VA HM see 2 light 12 cm apart.

H)- Electrophysiology :-

* Resting potential :-

- it's the difference between electric potential in cornea & retina = about 6 millivolt (cornea is +ve in relation to retina) due to unequal distribution of ions on both sides of the cell membrane.
- it' based on metabolic activity of RPE.
- it's independent of ERG.
- when discovered 100 years ago → the knowledge about electrical response of visual retina developed.

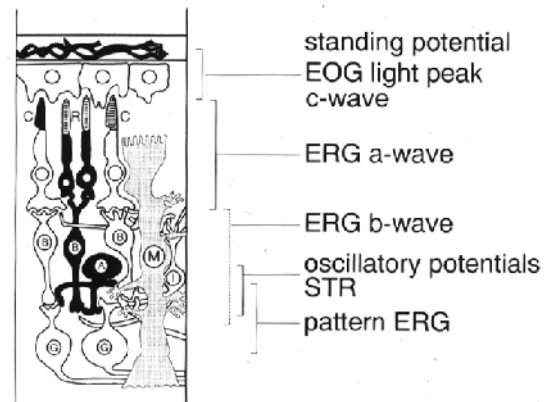


* Electro-oculogram (EOG):-

* **Def.:-** potential changes in the retina while the retina is at rest, it's generated at the interface between RPE & photoreceptors.

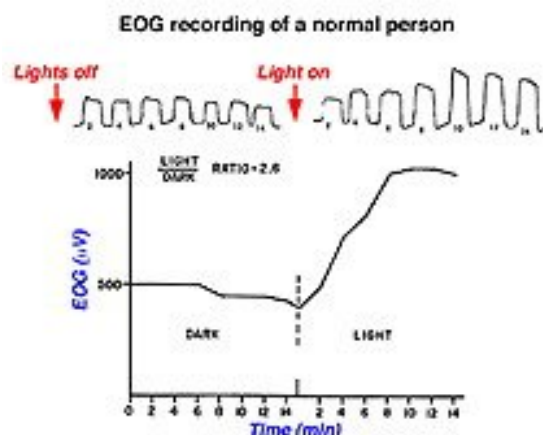
* **Principle :-**

- voltage difference between outer & inner poles of the eye (cornea & retina) resting potential is about 6 millivolt.
- an electrical current continuously flows from retina towards the cornea producing an electrical field around the eye.
- the algebraic sum of potential changes in the retina when recorded while the retina is at rest is called EOG.
- the amplitude of the response depend on illumination :-
 - a)- dark adaptation :-
 - response ↓ gradually till reaching dark trough after 8 - 12 min.
 - b)- light adaptation :-
 - response ↑ gradually till reaching light peak (spike) after 6 - 10 min.



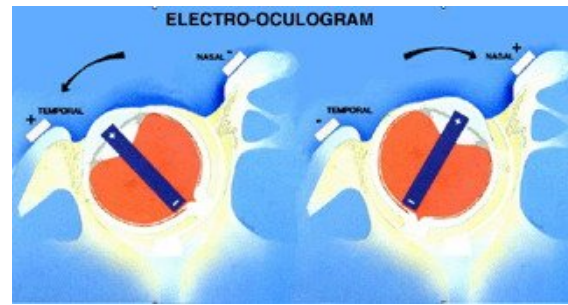
Normally = $\frac{\text{Light Peak}}{\text{Dark Trough}} = 2 \text{ (or } \geq 1.8 \text{)} \rightarrow \text{Arden ratio.}$

- abnormal if < 1.65 .



* Technique :-

- apply 2 electrodes, one on skin near the inner canthus & one on skin near the outer canthus.
- ask the patient to move his eyes by changing fixation between 2 red lights separated from each other by 30° , so when the +ve cornea approaches one electrode the -ve retina approaches the other electrode & potential difference is recorded & amplified by an amplifier or a pen recorder.
- all the above is done in dark & once in light & each has period of 15 min.



* Clinical significance :-

- any abnormalities detect abnormal presynaptic function of the retina :-

I)- EOG passes parallel to ERG :-

- i.e. any abnormalities in ERG, the EOG will be abnormal also except in (early changes in EOG before ERG) :-
- a)- *vitelliform macular dystrophy (Best's disease) :-*
 - ERG is normal but EOG is abnormal.

b)- *Albi punctate flavimaculatus.*

II)- Abnormal EOG (abnormal

Ardan ratio) :-

- vit.A ↓.
- retinitis pigmentosa.
- night blindness.
- chloroquine retinopathy.

III)- EOG used as a substitute for ERG in :-

- pediatrics.
- intolerance to contact lens (electrode) used in ERG.

IV)- regulation of dose of chloroquine in ttt of malaria :-

- by detecting early toxicity in RPE.

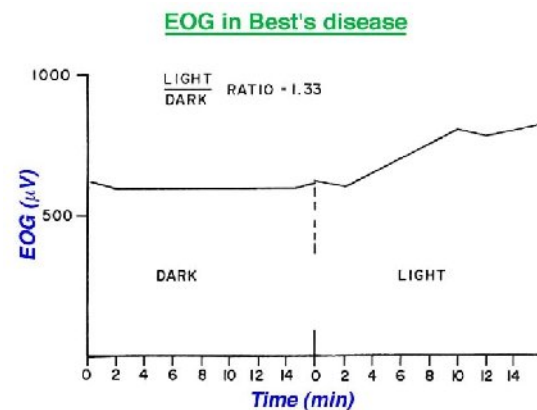


Fig. 49. EOG from a patient with Best's disease.

* Early Receptor Potential (ERP):-

- need very intense (10^6 brighter than that required to elicit ERG) short stimulus + special contact lens.

- Components :-

a)- *latent period* :- 0.8 sec.

b)- *R - wave* :-

- precede a - wave.
- biphasic i.e. +ve R1 & -ve R2.
- R1 → correspond to formation of metarhodopsin - I in cones.
- R2 → correspond to formation of metarhodopsin - II in rods.

N.B. ERP is generated by current crossing the outer cell membrane of outer segment since most of the cone opsin is present in this membrane & only a small fraction of rhodopsin is present.

- Amplitude :- depends on :-

- concentration of unbleached in photoreceptors outer segments.
- orientation of visual pigments in outer segments.
- orientation of outer segment membrane.
- chemical environment of photoreceptors.

N.B. 80% of amplitude is generated by cones & 20% generated by rods.

- Response :-

a)- *photostable component (5% of response):-*

- generated by stimulation of melanin pigment in RPE.

b)- *photoliable component (95% of response):-*

- generated by outer segments of photoreceptors.

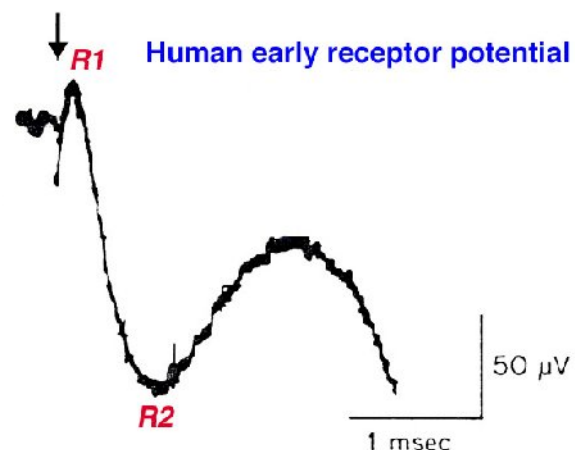


Fig. 10. Figure 10: A typical early receptor potential (ERP) of the human eye that was elicited by a very bright light flash (arrow). Two waves are identified: the positive R1 followed by the negative R2 (Yonemura and Kawasaki, 1967).

* Electroretinogram (ERG):-

- def.:- record of bulk electrical response of retina on exposure to a flash of light.

* Factors affecting ERG :-

- *stimulus* :- intensity, duration, wave length & frequency.
- *receptors* :- level of dark/light adaptation of retina.

* Technique :-

- patient is placed in a dark room for 30 min. (dark adaptation).
- full dilatation of the pupil not to affect retinal illumination by changing pupil size.
- light is delivered uniformly throughout the entire retina to stimulate all receptors.
- record electric response of retina by using :-
 - a)- a corneal contact lens probe (electrical).
 - b)- other neural electrode over forehead or cheek.
- response in the form of waves are amplified & recorded on X - Y plotter.

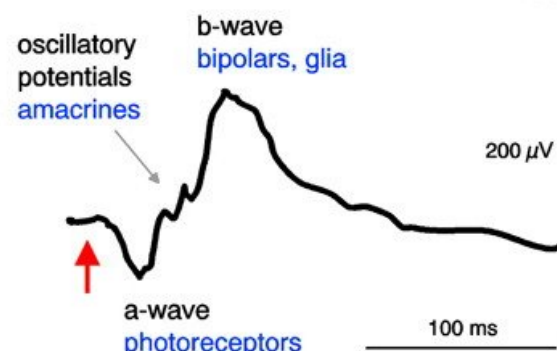
* Components :-

I)- a - wave :-

- -ve wave.
- latent period is 2 millise.(means that synapses are not involved) → this is confirmed by general resistance of response to poisons, alcohol & anoxia.
- amplitude is 100 μ Volt.
- immediately follow ERP.
- originated from inner segment of photoreceptors, evidenced by :-
 - a)- feeding mice with glutamate (destroy bipolar & ganglion cells) → intact

The single flash Ganzfeld Electroretinogram

FIG. 2A



- a - wave & absent b - wave.
- b)- rats deficient in vit.A → absent a - wave.
- c)- the only wave recorded in fovea.
- d)- mxm response when electrode put on outer segment of the retina.
- 2 parts :-
 - a)- a_1 → from cones i.e.
 - a - photopic.
 - b)- a_2 → from rods i.e.
 - a - scotopic.
- related to retinal attachment, so :-
 - a)- *partial (subtotal) RD* → ↓ amplitude of a - wave.
 - b)- *gross (total) RD* → absent a - wave.

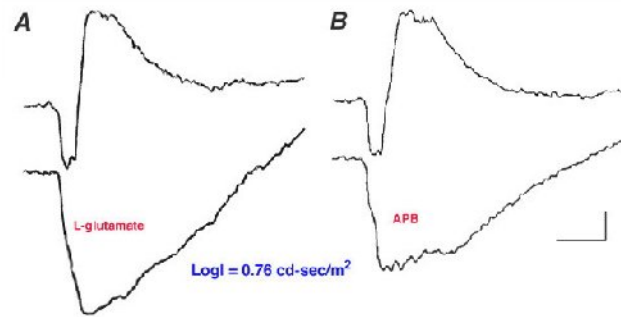
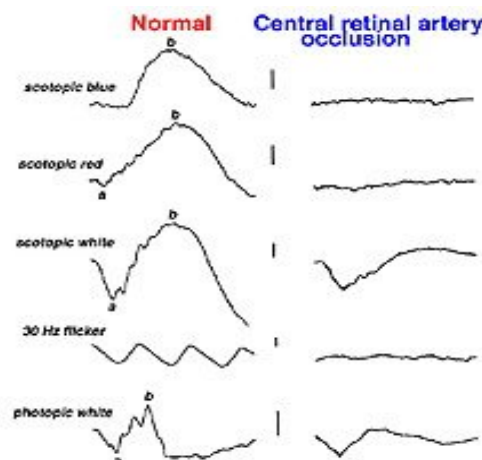


Fig. 6. Elimination of the ERG b-wave (F-II) in rabbits by intravitreal injection of L-glutamate (A) or 2-amino-phosphonobutyric acid (APB) (B). The experimental drug was injected into the right eye (lower trace) and saline into the left eye (upper trace) as a control. In both experiments, the drugs successfully eliminated F-II thus, revealing the entire time course of the F-III component.

II)- b - wave :-

- +ve wave.
- most important element in ERG & it varies with the intensity of the stimulus.
- amplitude is 100 - 300 μ Volt.
- follow a - wave.
- originates from bipolar cells directly or through Muller's cells in inner nuclear layer.
- 2 parts → b_1 → from cone dominated bipolar cells.
→ b_2 → from rod dominated bipolar cells.
- related to intra-retinal diseases :-
 - a)- Na^+ glutamate injection → ↓ amplitude of b - wave due to affection of bipolar cells.
 - b)- CRAO & CRVO → absent b - wave.

N.B. atrophy of ganglion cells & nerve fibers have no effect on b - wave.



III)- c - wave :-

- +ve wave.
- affected by size of the pupil & level of dark adaptation.
- originate from RPE (hyperpolarization) or from rods as spectral sensitivity of dark adapted c - wave corresponds with absorption spectrum of rhodopsin not that of melanin.
- abnormal RPE diseases → RPE separation & iodide toxins.
- c - wave persists in the atropinized eye & therefore obviously of retinal origin.

IV)- d - wave :-

- +ve wave & of short duration.
- start after cessation of the stimulus denoting an off-effect.
- not present in human eyes except in cases of aphakia when more short wave lengths can reach the retina.

N.B. according to Gravit studies, components of ERG are :-

- 1)- P-I → correspond to c - wave.
- 2)- P-II → correspond to b - wave.
- 3)- P-III → correspond to a - wave.

V)- e - wave :-

- is oscillation in ascending limb of b - wave, originating from amacrine cells & this e - wave is abnormal in microvascular abnormalities in mid-retina (inner nuclear layer).
- diabetic retinopathy → abolish e - wave according to level of ischemia.

*** Clinical significance of ERG :-****I)- Abnormalities in b - wave :-**

- a)- *supernormal b - wave (> 350 μV):-*
 - e.g. in retinal edema due to irritation of bipolar cells.
- b)- *Subnormal b - wave (< 100 μV):-*
 - e.g. in progressive retinitis pigmentosa.

c)- -ve b - wave :-

- absent b - wave with marked a - wave as in retinal vascular diseases e.g. CRAO & CRVO.

d)- Extinguished b - wave :-

- all elements of ERG are absent e.g. failure of retinal functions except in advanced glaucoma & optic nerve atrophy where ERG may be normal.

II)- ERG in retinal diseases :-

a)- Retinal degeneration :-

- ↓ amplitude & delayed b - wave.

b)- Retinitis pigmentosa :-

- stationary type → normal cone segment (b1), normal cone implicit time & abnormal rod function (b2).
- progressive type → subnormal b - wave.

c)- Retinal vascular diseases :-

- subnormal or absent b - wave, but if retinal edema occurs → supernormal b - wave.

d)- Retinal detachment :-

- subtotal → ↓ amplitude of a - wave.
- total → absent a - wave.

c)- Siderosis :-

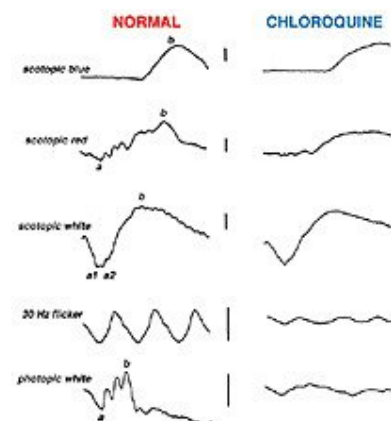
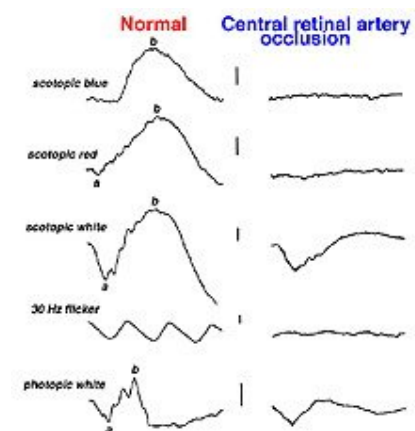
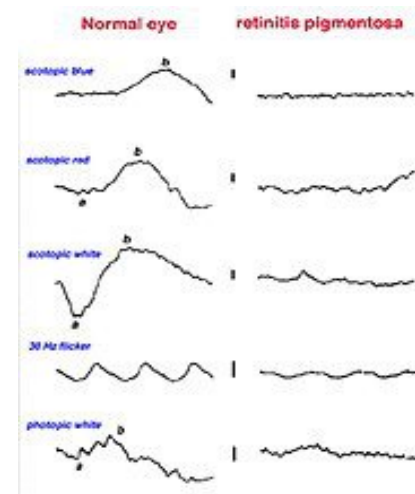
- if ERG is pathological → this indicate that FB must be removed.

d)- Chloroquine intoxication :-

- abnormal ERG in advanced cases.

e)- Vit.A ↓ :-

- subnormal or extinguished.



III)- Testing of macular functions :-

- here the stimulus should stimulate cones only.

- i.e. stimulus → red light subtending visual angle 2°.
- patterned.
- flickering > 20 cycles/sec.
- small to stimulate macula only as can as possible.

* Advantages of ERG :-

- a)- testing retinal functions in pediatrics, malingering & in opaque media.
- b)- since a, b & c - waves arise from cells distal to ganglion cells, ERG can be combined with VEP to differentiate lesions involving outer layers of retina from lesions involving visual pathway from ganglion cells to cortex.
- c)- distinguish cone functions from rod functions :-
 - 1)- use red flash → stimulate cones.
 - use blue flash → stimulate rods.
 - 2)- using flickering of light as rod can respond up to 20 cycles/sec., but cones can respond up to 60 cycles/sec.

N.B.

I)- Responses in ERG :-

- *supernormal* → *irritative stage.*
 - *normal a - wave & high b - wave.*
- *normal.*
- *subnormal* → *only a - wave is present.*
- *extinguished* → *flat ERG.*
- *-ve response of ERG* → *absent b - wave* → *CRVO.*

II)- ERG in Retinitis pigmentosa :-

- *rods & cones ERG b - wave implicit times are normal in sector retinitis pigmentosa.*
- *rods & cones ERG implicit times or both are markedly delayed in the early stages of widespread retinitis pigmentosa before any fundus changes are observed.*
- *normal cone implicit time with abnormal rod function is seen in stationary forms of night blindness.*

III)- ERG in Glaucoma :-

- ERG is normal as glaucoma affect ganglion cells only.

* Types of ERG :-

I)- Flash ERG :-

- media opacity - stimulus $> 20 \times 10^3$.

II)- Pattern ERG :-

- differs from flash ERG as it can measure ganglion cell activity.
- components :-
 - a)- P_{50} :- +ve wave - indicate macular function.
 - b)- N_{95} :- -ve wave - indicate ganglion cell function.
- clinical significance :-
 - a)- abnormal $P_{50} \rightarrow$ abnormal macular function.
 - b)- optic nerve disease $\rightarrow$ only affect N_{95} , so pattern ERG differentiate between maculopathy & optic neuropathy.
 - c)- diagnosis of early glaucoma & distinguish it from cases of ocular hypertension.

III)- Focal ERG :-

- light is directed to a small area of the retina e.g. fovea.
- clinically used to assess macular function.
- less commonly used $>$ pattern ERG.
- uses red light with $\uparrow$ intensity.

IV)- Dynamic ERG :-

- ascending limb of b - wave divided into 2 halves.

V)- Multifocal ERG :-

- early diagnosis of glaucoma.

VI)- Flickering ERG :-

- elicit cone function.
- > 2 cycles/sec.

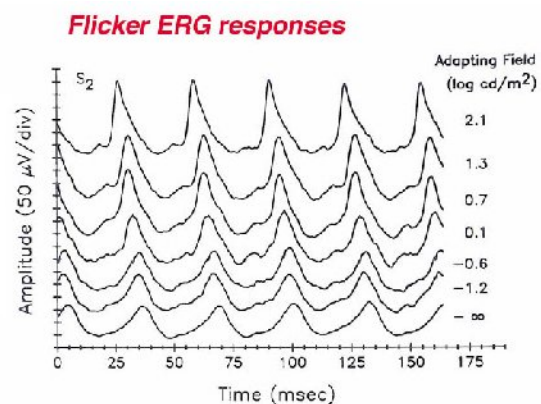


Fig. 20. Flicker ERG responses to stimulation at 31.1 Hz with a stimulus intensity of 0.8 log cd-s/m². The lowest trace was obtained in the dark-adapted state. Other traces were recorded after 30 min adaptation to white background of intensity denoted on the right (Peachey et al., 1992).

* Visual Evoked Response (VER):-

- def.:- VER is a diffuse electrical signal generated by occipital cortex in response to stimulation of retina by a light stimulus & this light stimulus may be either :-

a)- *pattern of media clear* → arise from V_1 .

b)- *flash of opaque media* → arise from area V_2 .

* Principle :-

a)- *Assesment of retino-cortical conduction :-*

- from ganglion cells → visual cortex.

b)- *Assesment of macular function :-*

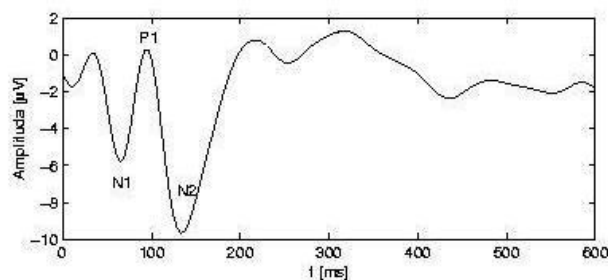
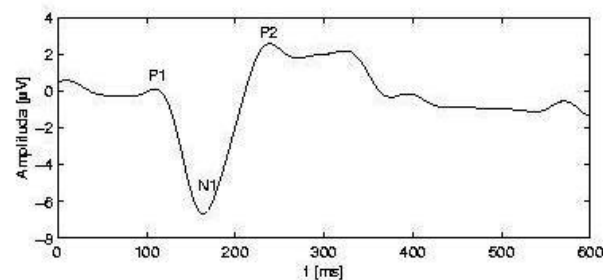
- as macula is represented in cortex by large area more than its retinal size (about 1000 times).

* Components :-

I)- Flash VER :-

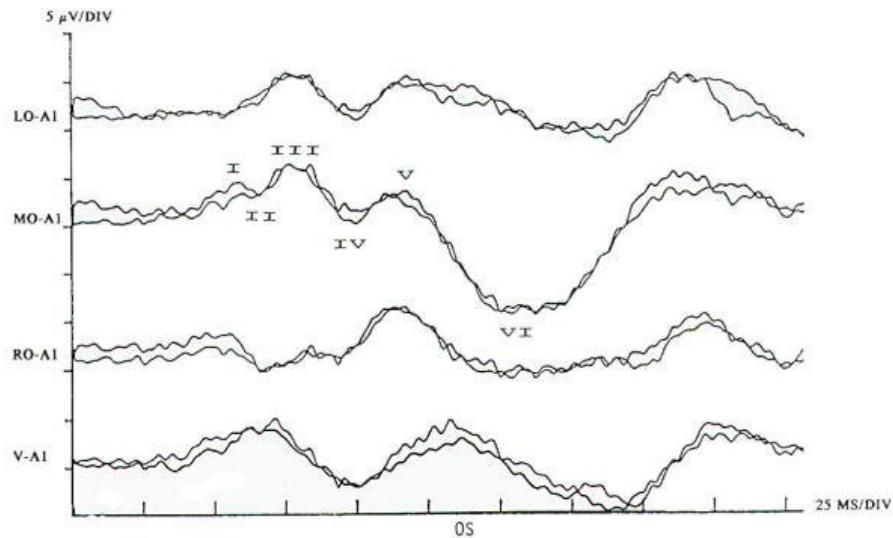
- stimulus is a flash of light.

- $N_1, P_1 - N_2, P_2 - N_3, P_3$.



II)- Pattern VER :-

- stimulus is black & white board pattern.
- essentially monophasic.



* Technique :-

- 6 electrodes are placed on occiput.
- common reference more anteriorly each electrode give separate wave of different amplitude.
- the amplitude is lower than that of ERG, so should be amplified & isolated from ERG noise.

* Clinical significance :-

- detect VA in → malingering.
→ child & infants.
→ mental retardation.
- detect & locate visual field defects.
- confirm diagnosis of subclinical & clinical optic neuropathy as all components are delayed & smaller (delayed transmission → slow transmission through optic nerve e.g. multiple sclerosis).
- assess integrity of macular function & hence VA e.g. children before surgery.
- in association with ERG to differentiate between outer retinal lesion from retinal lesion affecting ganglion cells up to visual cortex.

- cortical blindness → concussion of occipital cortex.

N.B. in amblyopia → ERG is normal while VER is abnormal.

* Response of optic nerve fibers :-

- fibers responding immediately after light is switched on & its response stop when light is switched off → they are 20% of nerve fibers called *on - fibers*.
- fibers responding only when light is switched on & respond again when light is switched off (no activity during the period of illumination) → they are 50% of fibers called *on - off fibers*.
- fibers show no response to light but respond when light is switched off → they are 30% of fibers called *off - fibers*.

* Electrophysiology of different layers of the retina :-

I)- RPE :-

- has potential of 20μV.
- due to active transport of ions (Cl^- & HCO_3^-) from retina to choroid.
- disappear if RPE is toxicated by Na^+ iodide.
- if electrode is put at a distance from RPE → this potential is recorded due to intercellular junctions.

II)- Photoreceptors :-

- hyperpolarization of 3 μV which continue with the stimulus & disappear with its disappearance.
- due to decomposition of visual pigments → liberate Ca^{++} ions which enter the cell → ↑ polarization.
- rods hyperpolarization is slower than that of cones.

III)- Bipolar cells :-

- some hyperpolarize & others depolarize.

IV)- Horizontal cells :-

- always hyperpolarize.

- produce slow graduated potential of 2 types after latency of 15 sec.:-
 - a)- *type L potential* :- amplitude affected by luminosity.
 - b)- *type C potential* :- amplitude affected by wave length by either hyper- or depolarization.

V)- Muller's cells :-

- depolarization, Muller's cells do not transmit visual sensation.

VI)- Ganglion cells :-

- 3 types of ganglion cells according to their light response :-
 - a)- *on-cells* 20%.
 - b)- *off-cells* 30%.
 - c)- *on-off cells* 50%.
- 2 types of ganglion cells according to colour recognition :-
 - a)- *spectrally non-opponent cells* :- respond either by excitation or inhibition to all wave lengths.
 - b)- *spectrally opponent cells* :- 4 types.

i)- Visual field & Perimetry :-

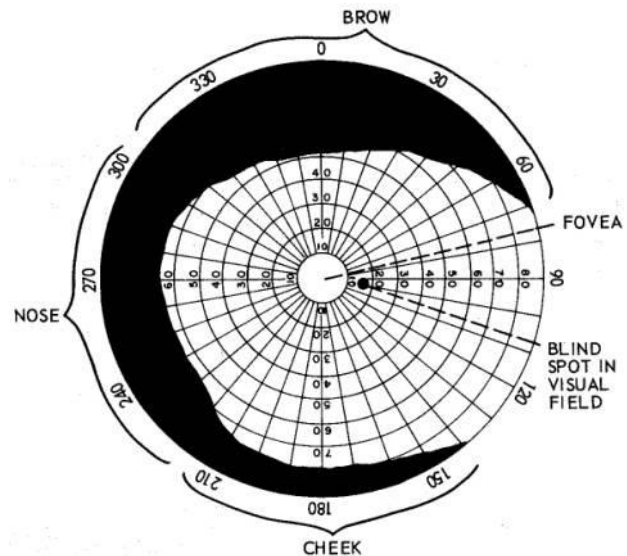
- it's convenient to imagine the visual field as an island of vision surrounded by a sea of darkness. It's not a flat plane but a 3 dimensional structure.
- the VA is most acute at the very top of the island & then declines progressively towards the periphery.

* Visual Field :-

- def.:- it's the area in space in which objects are visible during fixation.
- it's limited upward, inward & downward by the prominence of the brows, nose & cheek & also by the depth to which the eye is sunk in the orbit.

* Extent :-

- about 50° up, 70° down, 60° nasal & 90° temporal.
- it's largest for blue, smaller for red & smallest for green (blue > red > green).
- this depend upon the light energy reaching the retina.



* Blind spot :-

- it's the projection of optic nerve head (papillae) inside the visual field.
- it's vertically oval, 5.5° width & 7.5° height.
- situated 15° temporal to the fixation point & 1.5° below the horizontal meridian.
- it's totally blind (absolute -ve scotoma) & surrounded by an amblyopic area of 1° for white.
- it's not seen due to :-
 - a)- overlapping of the field.
 - b)- the blind spot is away from the visual axis.
 - c)- the eye is never steady.

* Impairment of the field may be either :-

- *in the receiving retinal cells* :- characterized by relative yellow-blue blindness e.g. RD & chorioretinitis.
- *in the conducting fibers* :- characterized by defective recognition of red & green.
- *in the occipital cortex*.

* Field defect :-

- it's an area of $\downarrow$ sensitivity.

* Abnormalities in the visual field :-

I)- Contraction :-

- complete blind area connected with other blind area outside the field & continuous with it, may be concentric, half or irregular.

II)- Depression :-

- area within the field in which light sensitivity depress.

III)- Scotoma :-

- isolated island of ↓ sensitivity within the field (e.g. blind spot) surrounded by normal visual function.

- it may be :-

a)- +ve → patient complains of them as black spots in the visual field.

b)- -ve → patient does not feel them, but doctor can find them as sign.

- -ve scotoma may be :-

1)- *relative* → loss of perception of certain colours over this area.

2)- *absolute* → loss of light perception.

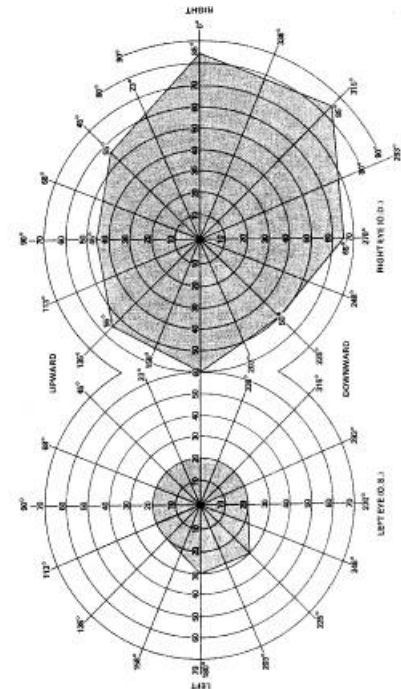


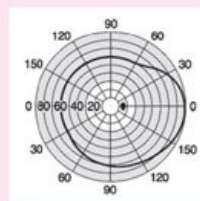
Figure 1. Chart of visual field showing normal field right eye and abnormal contraction visual field left eye.



ASSESSMENT TIP

Locating scotomas

Scotomas, or "blind spots," are classified according to the affected area of the visual field. The normal scotoma—shown in the temporal region of the right eye—appears in black in all the illustrations.



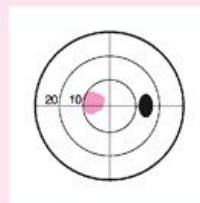
The *normally present scotoma* represents the position of the optic nerve head in the visual field. It appears between 10 and 20 degrees on this chart of the normal visual field.



A *central scotoma* involves the point of central fixation. It's always associated with decreased visual acuity.



A *centrocecal scotoma* involves the point of central fixation and the area between the blind spot and the fixation point.



A *paracentral scotoma* affects an area of the visual field that is nasal or temporal to the point of central fixation.



An *arcuate scotoma* arches around the fixation point, usually ending on the nasal side of the visual field.



An *annular scotoma* forms a circular defect around the fixation point. It's common with retinal pigmentary degeneration.

* Factors affecting the Differential Light Sense (D.L.S.):-

I)- Stimulus factors (extrinsic factors):-

a)- illumination of the background :-

- $\uparrow$ DLS $\rightarrow$ $\uparrow$ luminance (photopic background), so photopic field vision is wider than mesopic & scotopic vision.

b)- size of the object :-

- affect the size of the retinal image.
- $\downarrow$ DLS $\rightarrow$ $\uparrow$ size because large objects stimulate large number of photoreceptors.

c)- luminance (intensity) of test object :-

- $\uparrow$ DLS $\rightarrow$ $\uparrow$ intensity (within limits).
- with constant background illumination, the test will be seen easier the more it's brighter, therefore smaller brighter test can have the same effect as larger less bright test ($L \times S = \text{constant}$) due to spatial summation caused by interneuronal connections that add stimuli.
- this is disturbed in retinal edema.

d)- duration of presentation of test in static perimetry :-

- should be 0.5 sec. at least to be perceived & not > 1 sec. to avoid local adaptation which modifies retinal sensibility.

e)- speed of presentation of test in kinetic perimetry :-

- if very rapid, the threshold $\uparrow$.
- the optimum is to move the test $5^\circ/\text{sec}$.

f)- colour of the test :-

- colour sense varies in field of vision in an unexpected manner.
- the field is narrower with red & varies in different meridians.
- $\uparrow$ DLS $\rightarrow$ blue $>$ red $>$ green.

II)- Receptor (intrinsic) factors :-

a)- area of retina :-

- because of the double nature of retinal receptors & according to background illumination we test the cones (photopic) or the rods (scotopic) or both (mesopic).
- photopic light adapted $\rightarrow$ DLS mxm at fovea (centre).

- scotopic dark adapted → DLS mxm at 30o from fovea, there is central scotoma corresponding to the macula.

b)- retinal adaptation :-

- retinal sensibility reaches its optimum after sometime of adaptation to background illumination, otherwise the field will be narrower.

c)- pupil size :-

- mydriasis → ↑ field but within limits, optimal size is 3 mm.
- if > 6 mm → aberration & reflection.
- for comparing fields, the pupil size must be fixed.

d)- age :-

- after 50 yrs → ↓ retinal sensibility → narrower field.

e)- refraction :-

- in the peripheral field → no effect as it's compensated by spatial summation.
- in the central field → retinal image is unclear & cones are stimulated by subthreshold stimulus, so ametropia or presbyopia must be corrected.
- CL is the best way of correction as the frame of the glasses produce 5° - 10° scotoma in the peripheral field at about 65°.
- +lens → widening of the field.
- -lens → contraction of the field.

f)- features of the face :-

- big nose or ptosis → narrower field.

g)- co-operation of the patient.

*** Isopter :-**

- represent the limits of where given stimuli of same intensity is perceived.
- the location where the stimulus is the threshold stimulus.

*** Threshold :-**

- represent intensity of light stimulus that is perceived as 50% of time measured at a given retinal point.

*** Short term fluctuation :-**

- represents variability of threshold at at one time within one test (more common in glaucoma).

*** Long term fluctuation :-**

- represent variability of threshold at different times i.e. subsequent field may improve because of patient learning curve.

*** Perimetry :-**

- def.:- testing & evaluation of the visual field.

*** principle :-**

- every point in the visual field has a certain visual threshold defined as the weakest stimulus that is visible at that location.
- visual field testing consists of determining the visual threshold at selected points throughout the field of vision as well as determining the outside boundary of the visual field.
- in kinetic perimetry → selected test stimulus is moved until it crosses its isopter.
- in static perimetry → a stationary test stimulus in a given location is ↑ until it's seen.
- either method determine the visual threshold at one location (the location where the stimulus is just visible).
- the results are most often recorded in :-
 - a)- kinetic perimetry as isopters representing a contour map of the " hill of vision ".
 - b)- static perimetry as a graph of profile representing a slice through the " hill of vision ".

* Types :-

I)- Kinetic peimetry :-

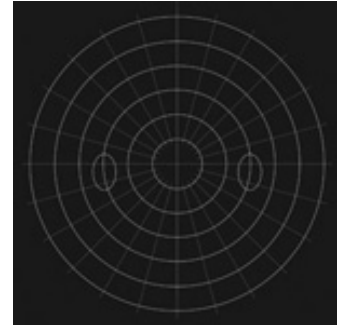
- 2 dimensional measurement of the hill of vision to obtain its boundary.
- test object or light spot is moved from periphery to center till seen by the patient's one eye.
- this is repeated in all principle meridians.
- the curved lines which join points of equal sensitivity is called isopters.
- several isopters are detected & measured.
- types :-
 - a)- arc perimetry.
 - b)- Goldmann or hemispherical. It's better as :-
 - it's similar to space seen.
 - test objects are controlled as regards size & brightness.
 - can change condition of examination & therefore better test for retinal sensibility & registering results.

II)- Static perimetry :-

- 3 dimensional measurement of the hill of vision to obtain boundaries & height.
- test light spots are non-moving stimuli of varying intensities (luminance) to obtain vertical boundary of the visual field.
- types :-
 - a)- suprathreshold perimetry :-
 - used for screening.
 - stimuli are of luminance level $>$ threshold.
 - detected stimuli are not indicative for grossly normal visual function while missed targets are indicative for $\downarrow$ visual sensitivity.
 - b)- threshold perimetry :-
 - used for detailed assessment of hill of vision.
 - stimuli are of threshold luminance & in different locations in the visual field.
 - we compare the results with normal age matched values e.g. Humphery perimetry.

III)- Campimetry :-**a)- Bjerrum screen :-**

- a plane black 1 m² screen at a distance of 1 meter from the patient.
- diffusely illuminated.
- test objects are series of white balls fixed on black sticks.



visual angle = _____ e.g. 1.5/1000

at 45° → angular size = 1/3 retinal size, so it's useful to test the central 35° of field only.

- b)- it's advised to do the test twice → one time under photopic condition (for central scotoma) & other time under mesopic condition (to test both rods & cones).

*** Humphrey perimetry :-****I)- Reliability indices :-**

- to what extent patient results are true & should be analysed 1st.

a)- fixation losses :-

- presenting a stimulus in the blind spot → if patient see it we record a fixation loss.
- ↑ no. of fixation losses → ↓ reliability of the test.

b)- false +ve :-

- recording of sound not light.

c)- false -ve :-

- patient cannot respond to suprathreshold stimuli at a location where sensitivity has been already recorded.

II)- Global indices :-

- used for measuring the progression of glaucomatous damage rather than for initial diagnosis.

- types :-

a)- Mean deviation :-

- measures overall field loss (elevation or depression).

b)- Pattern standard deviation (PSD):-

- measures focal loss.

- it's more specific for glaucomatous damage > mean deviation.

c)- Short term fluctuation :-

- variability of threshold at one time i.e. measured twice at the one time & get the difference.

d)- Corrected pattern standard deviation (CPSD):-

- variability of threshold after correction of short term fluctuation.

8)- Entoptic phenomena :-

- def.:- visualization of certain structures within the eye through proper arrangement of incident rays of light.

- these structures are not seen under normal circumstances.

* Types :-

- Entoptic phenomena related to clarity of ocular media.

- Haloes.

- Allied phenomena.

I)- Entoptic phenomena :-

a)- Opacity of ocular media :-

1)- Cornea & lens :-

- the opacity affects retinal image in ametropic eye > emmetropic eye.

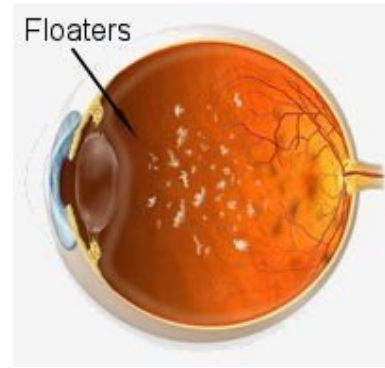
- the more the opacity is far from the retina → the less shadow on the retina → less interference with retinal image.

- lens & cornea are far from retina so the patient is unaware of these

opacities under normal conditions.

2)- Vitreous :-

- the closer the opacity to retina → the more the shadow on the retina → the more interference with the retinal image, so small opacities closer to the retina has a bad effect > large opacities far from the retina.
- the opacity which is seen by the patient is called musca volitans which is common in high myopes & appear as black spots or filaments against bright background & tend to sink down with gravity (so it's less in the morning due to miosis).
- vitreous opacities may be either :-
 - * harmless → patient reassurance.
 - * indicate PVD.
 - * indicate early RD → sudden onset of musca or sudden ↑ with flashes of light.
 - * represent torn piece of posterior part of hyaloids canal.



b)- Clear ocular media :-

1)- Tear film :-

- fluid produce a linear strip along upper lid margin specially if palpebral fissure is narrow.
- droplets of tear & mucous on cornea produce bright spots surrounded by dark rings, these spots move up & down with lid movement.

2)- Cornea :-

- epithelial folds due to pressure of upper lid on the cornea producing horizontal bands across the pupil, these bands move up & down with lid movement.
- stromal folds produce vertical bands.

3)- Lens :-

- a star is not seen as light spot but as star shaped due to lens structure which break up rays of light.
- this phenomena is related to suture lines of the lens.
- the radial fibers of the lens act as diffraction grating & produce

coloured haloes around light (similarly incipient cataract may produce haloes).

4)- Retina :-

** Retinal BVs :-*

- not seen under ordinary conditions of illumination because the visual elements are adapted to this pattern of illumination.
- seen when their shadows fall on visual elements under unusual illumination because visual elements are not adapted to this pattern of illumination.
- focusing of slit lamp beams on posterior part of sclera → black lace against red background.
- looking by the eye through moving pinhole disc shadow will fall on different receptors → avoiding of adaptation of receptors → BVs appear as dark branching lines against bright background surround the avascular central area (fovea is avascular).
- pressure on one eye specially under exercise → the pulsating retinal BVs can be seen due to mechanical disturbance of underlying receptors from exaggerated excursion of distended BVs, these pulsations are not seen in the macula (they are due to retinal not choroidal circulation).

** Retinal capillary circulation (Sheerer's phenomena):-*

- bright circles against dark background appear moving in short curved paths, these paths have the same arrangement of capillary loops.
- they appear suddenly & disappear suddenly if one looks to a brightly illuminated surface (white paper or cloudless sky). They are not seen in macular zone (no BVs).
- the cause of circles :-
 - * RBCs → evidenced by circles best seen on looking to a monochromatic light background of absorption spectrum of 350 - 450 nm which is same as absorption spectrum of Hb.
 - * WBCs → evidenced by long intervals between successive points.
- these corpuscles either move in the precapillary arterioles (more accepted) or in the deep capillary plexus.

*** Clinical significance of retinal entoptic phenomena :-**

- a)- *assessment of perifoveal circulation* in cases of atherosclerosis
(↓ pulsations of CRA or even disappear).
- b)- *measuring of FAZ* → 1.3° or 0.4 mm.
- c)- *pilocarpine* → disappearance of many perifoveal capillaries.
- d)- *entoptic visualization of the macula :-*
 - when one looks at a brightly illuminated plastic plate through a dichromatic filters for red & blue (one filter for red & another filter for blue).
 - a lailac ring of 18 mm in diameter will be seen with a clear granular center.
 - if blue filter is removed → the macula appears white on a red background.
- e)- *pressure on eye by opthalmodynamometry* with pressure 50 mmHg → ↓ movement of particles (i.e. absent Sheerer's phenomena).
- f)- *entoptic perimetry* used when ocular media is densely opaque & fundus examination is impossible, help to give prognosis in cases of cataract, before vitrectomy & keratoplasty.

II)- Haloes :-

- def.:- coloured rings surrounding stimulating light with blue next to stimulating light & the red is outermost.
- cause :- breakdown of white light by various media in the eye during passage of light to the retina.
- it may be physiological or pathological :-

I)- Physiological haloes (lenticular):-

- due to diffraction by lens fiber arrangement (radially grating).
- occurs when one looks at a candle flame through a thin layer of lycopodium powder enclosed between 2 glass plates (act as a trial lens).

II)- Pathological haloes :-

- chronic conjunctivitis with mucous secretions specially in the morning.
- intense exposure to light (e.g. snow blindness) due to conjunctivitis produced by exposure to UV rays.

- angle closure glaucoma due to corneal epithelium edema(→ change refractive condition of th cornea), usually observed after after exposure to dark.

N.B. How to differentiate between haloes of angle closure glaucoma & that of the lens ? by slit aperture → glaucomatous haloes remain intact while lens haloes become segmented.

III)- Allied phenomena :-

a)- Blue arcs of the retina :-

- dark room.
- fixate with one eye a point which is slightly temporal to a small rectangular light source → 2 small horizontal bands are seen as 2 blue bright light arcs radiating from source of light towards blind spot due to 2^{ry} stimulation of retinal nerve fibers.

b)- Self illumination of the retina :-

- sense of grayness under complete dark adaptation due to ↑ retinal sensitivity.

c)- Phosphenes :-

- def.:- flashes of light or photopsia due to non light stimulus :-
- 1)- *mechanical stimulus :-*
 - e.g. trauma applied to the eye.
 - vitreous traction on the retina or retinal tear → phosphenes are seen in the diagonal opposite side.
- 2)- *electrical stimulus :-*
 - weak electrical current → blue phosphenes.
 - strong electrical current → red or white phosphenes.
- phosphenes are seen in the same region of application of electrical current.

d)- Moore's lightening streaks :-

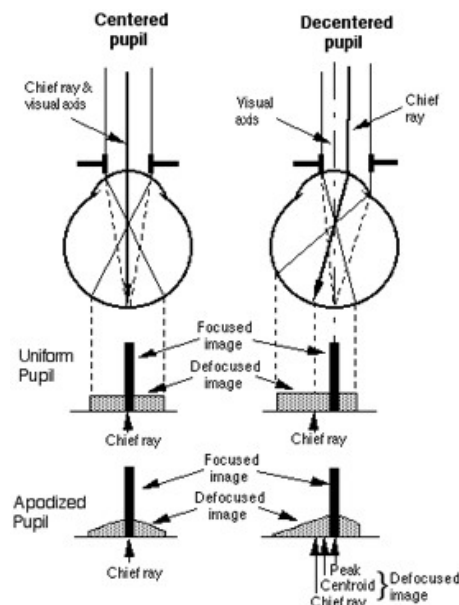
- vertical flashes seen on the temporal side of the eye due to vitreous opacities.
- common in ♀ > 40 years.

e)- Haidinger's brushes :-

- looking at a surface illuminated by plane polarized white light.
- yellow & blue brushes or sheaves are seen radiating from fixation point due to variation in absorption of light by macular yellow pigment in the foveal region, so disturbed orientation of macular pigments as in macular edema → disappearance of brushes.

**- clinical significance :-**

- 1)- disappear in CME, CSR & age-related macular degeneration.
- 2)- assessment of prognosis of amblyopia exotrophia i.e. if patient see brushes → good prognosis after eye occlusion.
- 3)- ttt of eccentric fixation with training the patient to fixate his eye on brushes which are seen by fovea only.
- 4)- entoptic visualization of Stiles Crawford effect in myopes due to tilting of foveal cones by contour of the fundus → patient see bright star out of focus.



9)- Extra-Ocular Muscles

(EOM):-

* Anatomical consideration :-

- there are 2 types of muscle fibers :-

I)- Twitch single innervated fibers (thick):-

- contain little mitochondria (i.e. anaerobic metabolism) → rapid response to the stimulus with rapid contraction of high amplitude & short duration.
- responsible for saccadic eye movement & help fixation & pursuit movement.

II)- Tonic multiple innervated fibers (thin):-

- contain numerous mitochondria (i.e. aerobic metabolism) → slow response to the stimulus with slow contraction of low amplitude & long duration.
- responsible for gaze in all positions including 1st position.

- There are 2 types of innervations :-

I)- Motor :-

- number of fibers which are innervated by a single neuron axon is very small, this permits a high power of contraction & delicate regulation of eye movement.

II)- Sensory, sympathetic & proprioceptive.

- Large amount of elastic tissue allowing passive contraction of EOM when its tone ↓ allowing more delicate regulation of eye movement.
- The eye is not retracted back by tone of EOM due to presence of Tenon's capsule, check ligament & ligament of Lockwood which keep the eye in position.

* Physiological characters of EOM :-

I)- High muscle tone :-

- EOM can contract by 2 ways :-
 - a)- *with shortening (isotonic)* → movement of the eye & rotate the globe.
 - b)- *without shortening (isometric)* → fixation of the eye by co-contraction of the antagonist.

II)- Fatigue does not occur quickly :-

- due to intermittent contraction of individual muscle fibers.

III)- Muscle pain :-

- results from pulling on the muscle not from cutting or pricking.

IV)- Contain well developed proprioceptors :-

- allowing rapid & fine adjustment required for postural & fixation reflexes.
- the fine adjustment (*precised eye movement*) helps binocular vision (corresponding points of both retina project to the same point in space).

V)- Produce various types of eye movements :-

- & part of movement is under supranuclear control.

VI)- Innervated by cranial nerves :-

- 3rd, 4th & 6th CNs.

VII)- Physiological insertion :-

- each muscle before its anatomical insertion is rested on the globe & contact with it at a point called physiological insertion.
- this point is tangential & changed with each eye movement & make the EOM to exert a tangential force on the globe.

VIII)- Pharmacology of EOM :-

a)- Acetyl choline :-

- when acts on thick single innervated twitch fibers produce twitches & when acts on thin multiple innervated produce tonic prolonged contraction.

b)- Anti-cholinesterase :-

- e.g. eserine & prostigmine → twitches (i.e. short tetanic contractions).

c)- Neuro-muscular blockers :-

1)- *succinyl choline* → small dose → ↑ ms tone & does not ↓ twitches.
→ large dose → ↓ twitches.

2)- *botulinium toxins* :-

- small dose IM → interfere with A-ch release at motor end plate & alters contractility.
- uses of botulinium toxins :-
 - * alternative for strabismus surgery.
 - * prevent contracture of antagonist ms in paralytic squint.
 - * used in essential blepharospasm.

3)- *tubocurarine* :-

- compete with A-ch for receptors → block receptors without depolarization.

N.B. depolarizing blockers → *succinyl choline* & *botulinium*.

non-depolarizing blockers → *tubocurarine*.

4)- *Anesthesia* :-

- early stages → side movement.
- anoxia with anesthesia → eye looks down with rapid jerky eye movement.
- as the depth ↑ → ↓ movement & the eye is in the midline position.

5)- *Alcohol* :-

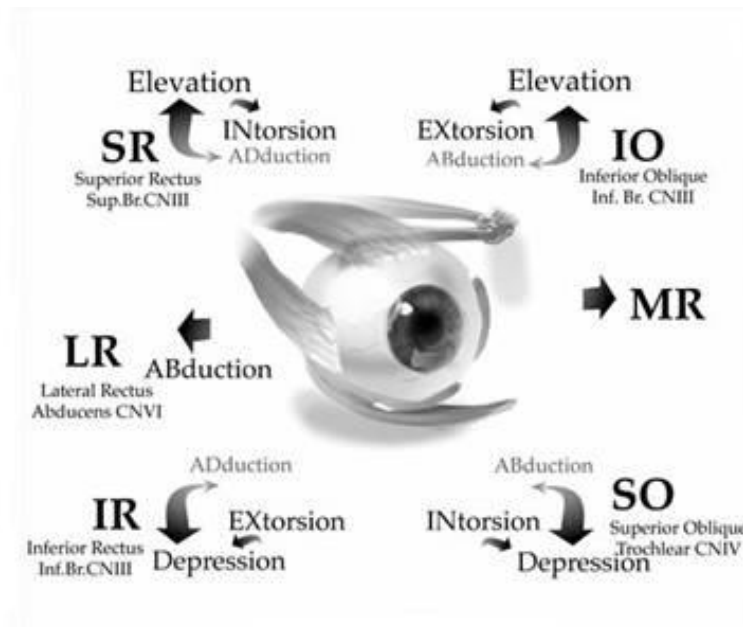
- diplopia due to release of the eye from visual fusional impulses.

IX)- Reciprocal innervation of antagonist of antagonist(Sherrington's law):-

- contraction of one ms is accompanied by relaxation of antagonistic ms.
- in some pathological conditions e.g. Duane's retraction \$, there is contraction of both MR & LR on trying to adduct the eye.

X)- Conjugate eye movement.

* Actions of EOM :-

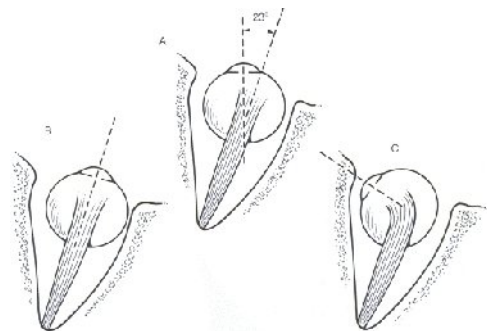


I)- Superior rectus (SR):-

- 1^{ry} action → elevation.
- 2^{ry} action → adduction & intorsion.

II)- Inferior rectus (IR):-

- 1^{ry} action → depression.
- 2^{ry} action → adduction & extorsion.



- All the above occur in the 1^{ry} position when ms make 23° with vertical meridian of the eye.
- When the eye is adducted farther 67° from its 1^{ry} position → the action will be intorsion & adduction for SR & extorsion for IR.
- When the eye is abducted 23° from its 1^{ry} position → the action will be only elevation for SR & depression for IR.
- When the eye is abducted > 23° from its 1^{ry} position → the action will be elevation, abduction & extorsion for SR & depression, abduction & intorsion for IR.

III)- Medial rectus (MR):-

- adduction.

IV)- Lateral rectus (LR):-

- abduction.

V)- Superior oblique (SO):-

- 1^{ry} action → intorsion.
- 2^{ry} action → depression & abduction.
- All above actions occur in 1^{ry} position when the ms makes angle 51° with vertical meridian of the eye.
- on adduction 51° → depression only.
- on abduction farther 39° from 1^{ry} position → intorsion & abduction.

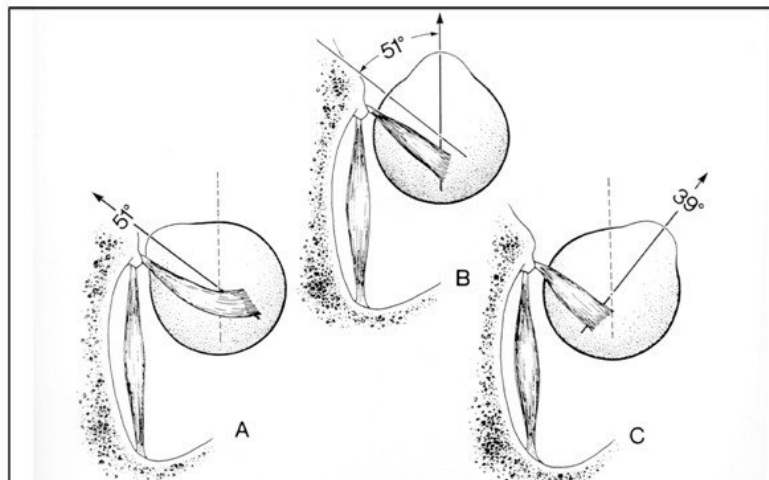
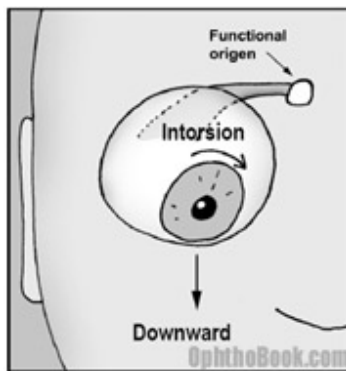
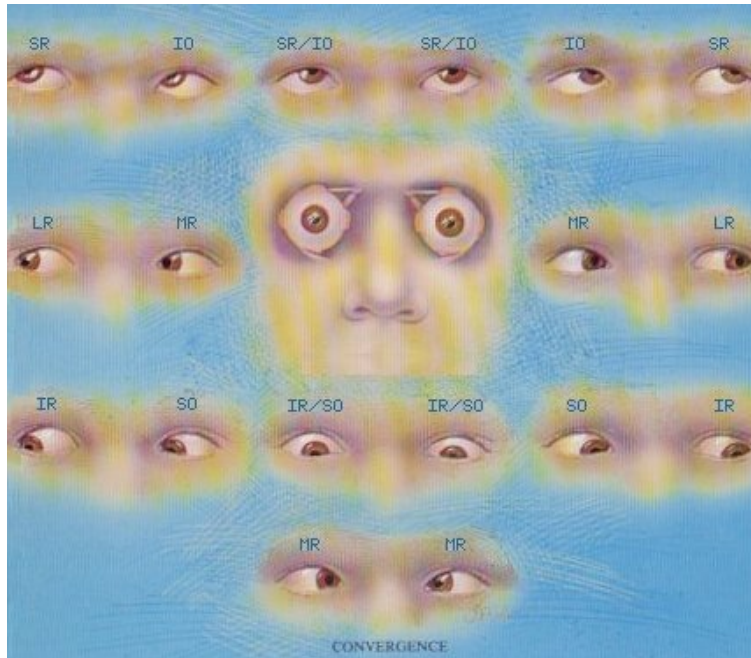


Figure 3. Anatomy of the superior oblique muscle. A: 51 degrees of adduction. B: primary position. C: 39 degrees of abduction.

VI)- Inferior oblique (IO):-

- the same as SO but angle in 1^{ry} position is 59°.
- 1^{ry} action → extorsion.
- 2^{ry} action → elevation & abduction.
- only elevation on adduction.
- if eye abducted 39° → pure extorsion.
- if eye adducted 51° → pure elevation.

* Combined muscle actions :-



I)- Vertical movements :-

- SR + IO → elevation.
- IR + SO → depression.
- only elevator in abduction → SR.
- only elevator in adduction → IO.
- only depressor in abduction → IR.
- only depressor in adduction → SO.

II)- Horizontal movements :-

- MR → adduction.
- LR → abduction.

* Eye movements :-

- *def.*:- any change from 1ry position (1ry position is the position when the head is erect & eyes are looking straight ahead).

- *Classification :-*

I)- Positions at rest :-

- absolute.
- relative.

II)- Uniocular :-

- ductions.
- torsions.

III)- Binocular :-

- conjugate → according to gaze.
→ according to speed → rapid (saccadic).
→ slow (pursuit).
- dysconjugate → convergence.
→ divergence.

I)- Position of rest :-

a)- Absolute :-

- eyes are released from all neuromuscular control e.g. death & total ophthalmoplegia.
- the eyes tend to diverge.

b)- Relative :-

- the neuromuscular control is intact but there's no stimulus e.g. blind eye.
- the eyes tend to diverge.

N.B. the exact alignment of both eyes is obtained by fixation & to achieve that 3 movements occur :-

- 1)- Jerky → every 1 - 15 sec.
- 2)- Oscillatory (fine oscillation).
- 3)- Minute variations in head position.

II)- Uniocular movements (rotatory movements):-

- center of rotation is 15.4 mm behind the cornea & 1.5 mm nasal to the geometrical center of the globe.

- *Types of uniocular movements :-*

a)- Ductions :-

1)- around vertical axis :-

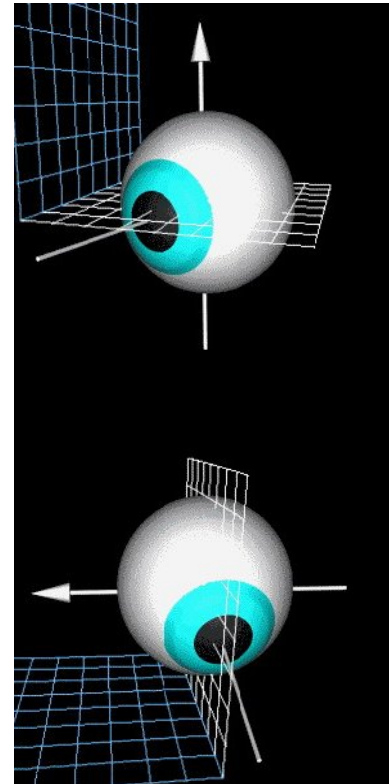
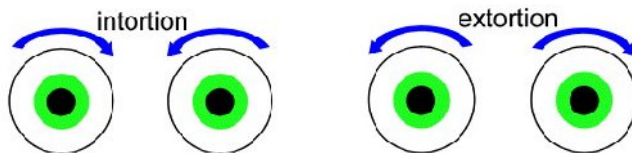
- adduction.
- abduction.

2)- around horizontal axis :-

- elevation (sursumduction).
- depression (dorsumduction).

b)- Torsions :-

- intorsion.
- extorsion.

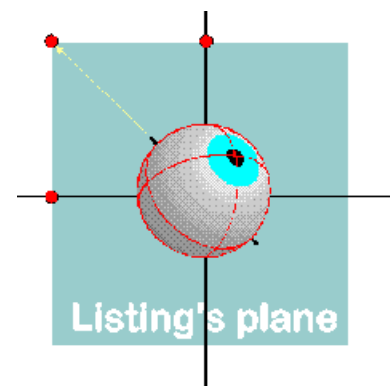


*** Donder's law :-**

- for any oblique movement there is a constant & definite degree of torsion (false torsion as there's no real rotation around anteroposterior axis).

*** Listing law :-**

- when we leave the 1ry position to any new position, the fixation line takes the shortest possible route.
- during changing to fixation, the eye rotate around a single axis of Listing plane which pass coronal through equator & not rotate around the anteroposterior axis.



III)- Binocular movements :-

a)- Conjugate (version movements):-

- coordinating movement of both eyes in the same direction (i.e. both axes remain parallel).

b)- According to gaze :-

- dextroelevation → Rt. SR & Lt. IO.
- levoelevation → Rt. IO & Lt. SR.
- levodepression → Rt. SO & Lt. IR.
- dextroversion → Rt. LR & Lt. MR.
- Levoversion → Rt. MR & Lt. LR.

c)- According to speed :-

- rapid (saccadic).
- slow (pursuit).

*** Hering's law of synergistic :-**

- in all voluntary eye movements there's equal & simultaneous innervations flow from oculogyric centers to pairs of synergistic muscles in both eyes.
- proved by electromyography.
- important in diagnosis of paralytic squint.

*** Supranuclear control of eye movement :-**

- Functions :-

- coordinate eye movements together.
- control response of the eyes to changes in target position & speed.
- control response of the eyes to changes in head position.

- Components :-

a)- Brainstem control centers (direction of movement):-

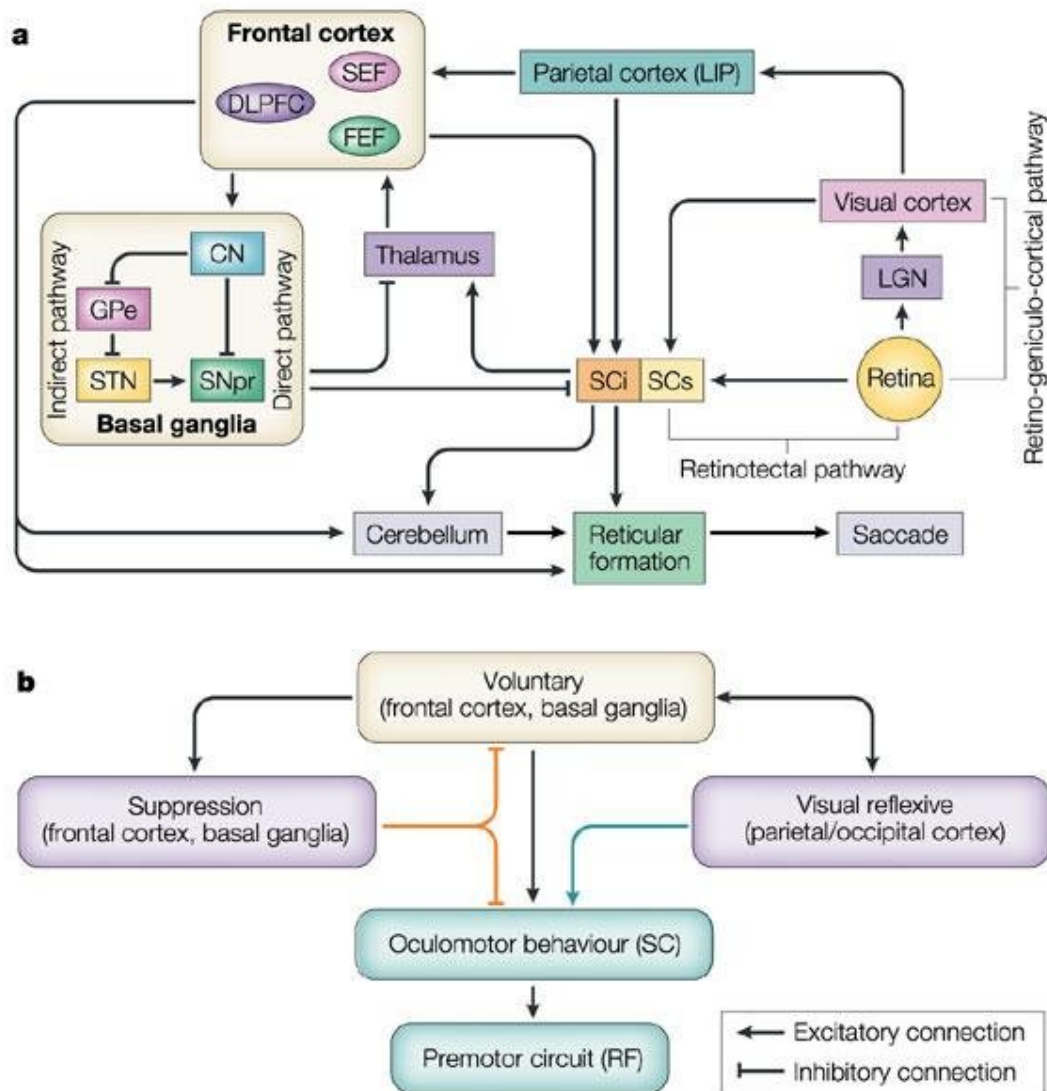
- paramedian pontine reticular formation (PPRF).
- medial longitudinal fasciculus (MLF).
- superior colliculus (SC).

b)- Cerebral cortex control centers (type of movement):-

- frontal eye field area 8 (FEF) → for voluntary eye movements.
- parieto-occipito-temporal junctions (POT).

c)- Basal ganglia & thalamus.

d)- Vestibular system.



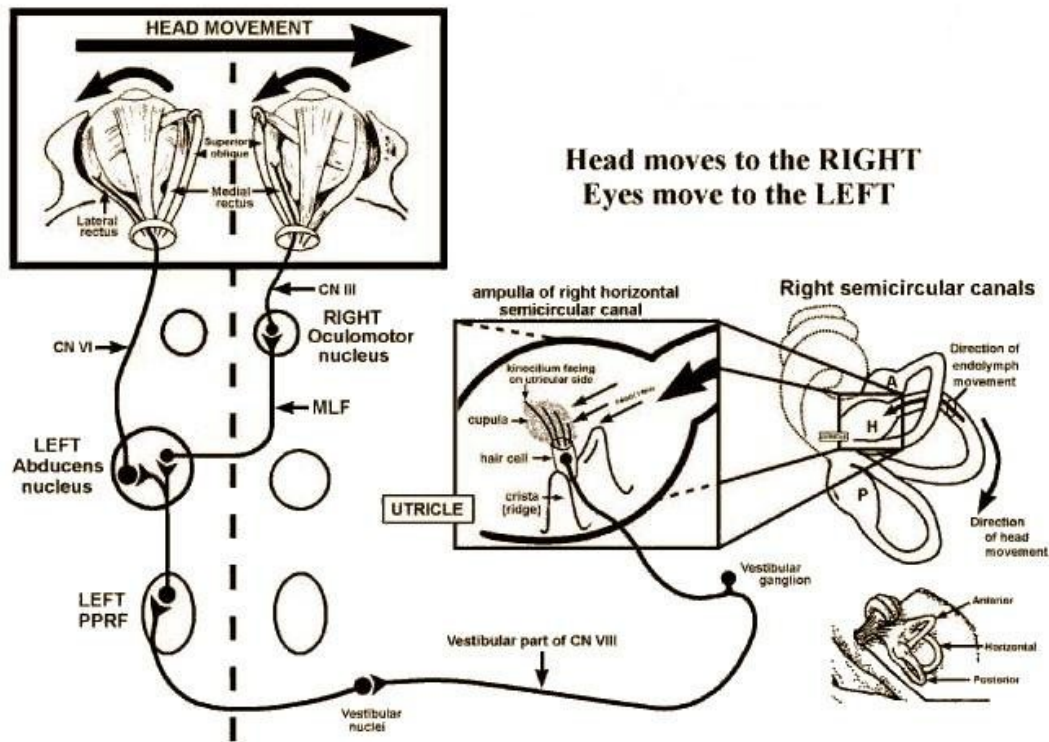
* Neurological control of EOM :-

I)- Tracking system :-

a)- Vestibular movements & vestibulo-ocular reflex :-

- * there's stabilization of retinal image inspite of changing environment or changing head or body posture.

- * latency 15 m.sec.
- * neutralized by saccadic movement when head & eyes move in the same direction together.
- * *Vestibulo-ocular reflex (VOR):-*



- maintain eye fixation during head & body rotation.
- 1)- Static VOR :-
 - mediated by utricle & saccule.
 - during head tilt the eyes are rolled during static head tilt to the opposite side of tilting e.g. chin elevation → eye moves down.
 - 2)- Dynamic VOR :-
 - mediated by semicircular canals.
 - during head rotation, slow movement in the opposite direction of rotation followed by fast movement in the same direction of rotation then again slow movement in the opposite direction of rotation.

* *Vestibular nystagmus* :-

- occur as discussed in dynamic VOR by stimulation of semicircular canals either by rotation or caloric test.
- Caloric test :-
 - 1)- warm 40°C → stimulation of ipsilateral canals → slow movement of eyes to the opposite side then fast movement to the same side.
 - 2)- cold 33°C → inhibition of ipsilateral semicircular canals → slow movement to the same side then fast movement to the opposite side.

* *Pathway of VOR* :-

- Hairy cells in the semicircular canals → vestibular nerve → upper medulla → ascending tract → vestibular nucleus → 3rd CN nucleus.

b)- *Saccadic eye movements* :-

- under contralateral supranuclear control (frontal eye field area 8).
- very fast voluntary movements.
- may be involuntary e.g. fast eye movements during dreams.
- occurs with changing fixation as during sudden appearance of object or hearing eccentric sound in the peripheral field.
- latency is 100 - 200 millisec.
- velocity is 800 - 1000 /sec.
- present at birth, precise & predetermined.

c)- *Pursuit eye movements* :-

- under ipsilateral supranuclear control (peristriate occipital cortex).
- slow movement in response to a moving object in space to maintain fixation on the fovea.
- when occur alternating with saccades → optokinetic nystagmus.
- latency is 120 - 150 millisec. (sensitive to drugs).
- velocity is $35 - 50^{\circ}/\text{sec}$.
- arc reflex but require visual attention.
- not present until 6 months of age.

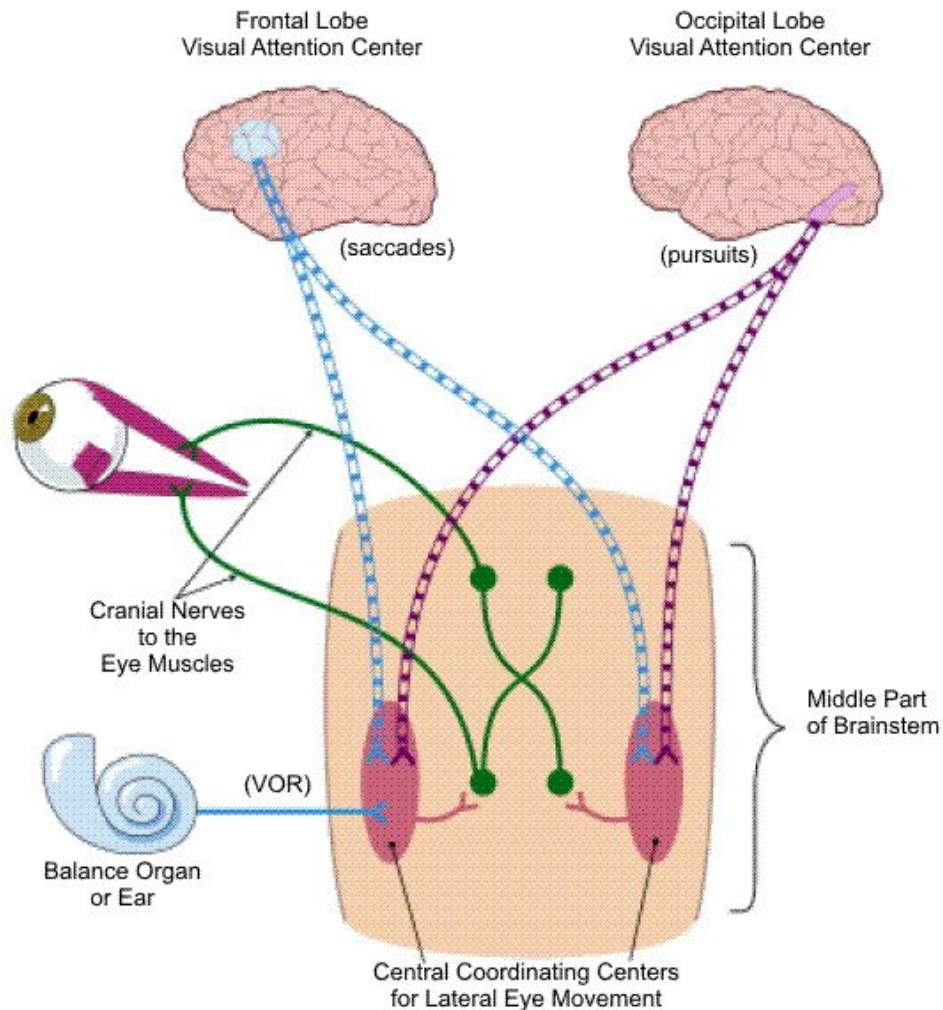


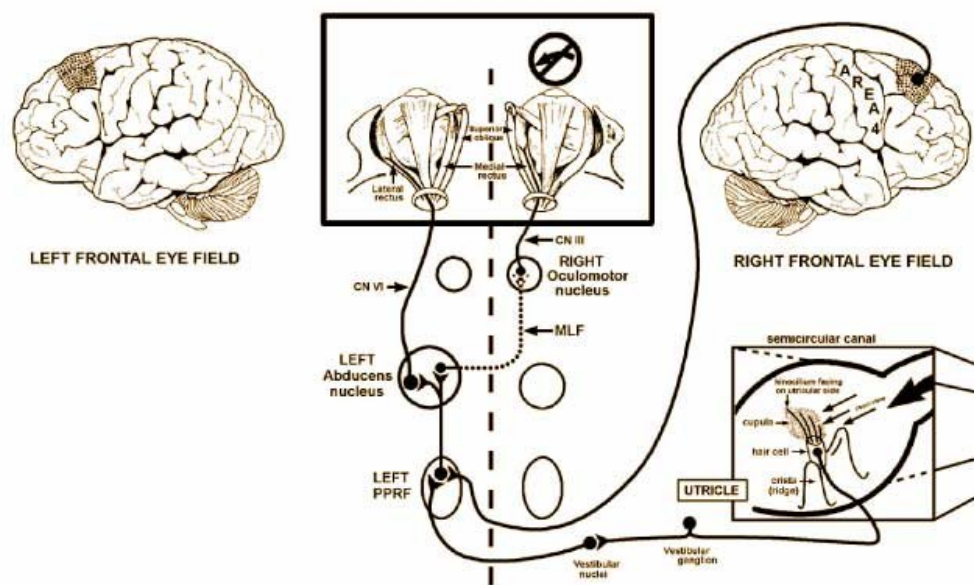
Fig. 4.3: Control of eye movements is a complex process involving several areas of the brain and the balance organ in the ear.

d)- Vergence & Fusional movements :-

- slow $\rightarrow 20^\circ/\text{sec}$.
- occurs reflexly as a result of the difference between the off-target error of each eye.
- stimulated by accommodation (accommodative vergence) & disparity vergence (fusion).
- latency is 150 millisec.
- velocity is $20^\circ/\text{sec}$.

II)- Ocular motor nerves, nuclei & internuclear connections :-

- EOM are innervated by III, IV & VI CNs.
- CNs III & IV nuclei are located on each side of midbrain & CN VI nuclei are located on each side of pons.
- the ocular motor nuclei are connected together & to the vestibular nuclei by the MLF which is connected to the reticular formations in the brainstem & to the cerebellum.
- MLF is linked to 3rd CN nucleus on the same side & to 6th CN nucleus on the opposite side.



Lesion of the RIGHT MLF = inability to turn the RIGHT eye past the midline to the LEFT = INTERNUCLEAR OPHTHALMOPLÉGIA (INO), No atrophy of the RIGHT medial rectus, Diplopia when attempting to look LEFT of the midline, also there is nystagmus of the LEFT eye

- Lesion in the MLF :-

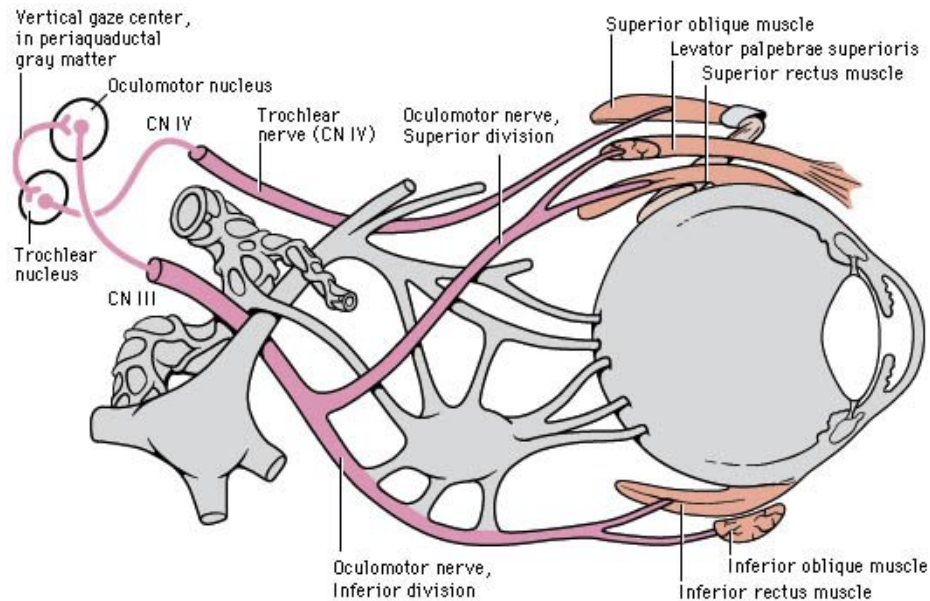
- loss of adduction on the same side.
- nystagmus on abducting the eye of the opposite side (on horizontal version).
- vertical nystagmus on elevation of both eyes.

- Gaze centers :-

- they are located in the brainstem near the ocular motor nuclei & lesion in these gaze centers lead to interference with binocular vision.

b)- center of lateral gaze (pontine paramedian reticular formation):-
located near the 6th CN nucleus → lesion lead to palsy of lateral gaze on the same side.

c)- center of vertical gaze (pretectal region):- near the superior colliculus & located near the 3rd & 4th CNs nuclei → lesion lead to palsy in vertical gaze (Parinaud's \$).



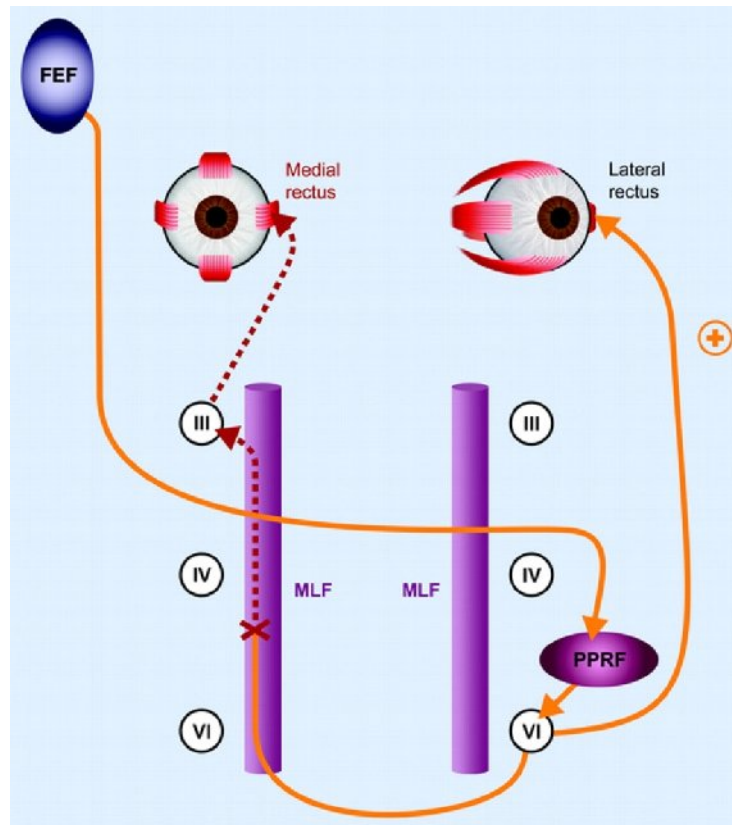
III)- Central organization (functional system of eye movement):-

a)- Vestibular system :-

- stabilize the retinal image inspite of head & body movement.
- center is MLF & vestibular nuclei.
- lesion → pathologic nystagmus.
- supranuclear lesion → doll's head phenomena.

b)- Saccadic system (fronto-pontine system):-

- center is the frontal eye field in area 8 on the other side.
- fibers decussate below the level of 4th CN nucleus & pass in pontine paramedian reticular formation & to MLF then to all motor nuclei.
- Rt. frontal eye field cause saccadic movement to the Lt. side.
- lesion → inability to move eyes to the opposite side.
- irritation → involuntary movement of the eyes to the opposite side.

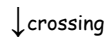


c)- Pursuit system :-

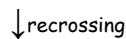
- enable the eye to track a moving target.
- center is the peristriate occipital cortex on the same side.
- peristriate occipital cortex → optic radiation



Superior colliculus



Fronto-pontine fibers



Pontine paramedian reticular formation

- lesion → pursuit defect on the same side.

N.B. this explains why stimulation of occipital cortex lead to eye movement to the same side.

d)- Vergence & fusion system :-

- for tracking in depth.
- center → peristriate occipital cortex.

IV)- Center of vertical eye movement :-

- in the brainstem near the superior colliculus & linked with 3rd & 4th CNs nuclei.
- lesion → difficult vertical gaze (more in upward gaze).
 - *Parinaud's \$ or Sylvian duct \$:-*
 - cause → pineal body tumour.
 - trauma & demyelinating diseases.
 - signs → difficult upward gaze with diplopia.
 - bilateral lid retraction on upward gaze.

*** Nystagmus :-**

- def.:- repetitive involuntary to & fro oscillatory eye movements (usually affecting both eyes).
- Classification :-

I)- Jerk nystagmus :-

- slow defoveating (drift) movement followed by fast saccade foveating movement.
- direction of nystagmus is described by the direction of the fast saccadic component e.g. Rt., Lt., up, down or rotatory.
- example → vestibular nystagmus.

II)- Pendular nystagmus :-

- both foveating & defoveating movements are slow.
- example → see-saw nystagmus of Maddox.
 - sensory deprivation nystagmus.

III)- Mixed nystagmus :-

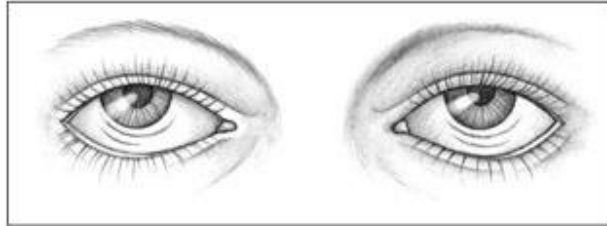
- pendular in primary position & jerk in lateral gaze.

N.B. Eye movements that point the retinal fovea at an object of interest are called foveating; those that move the fovea away from the object are called defoveating.

Classifying nystagmus

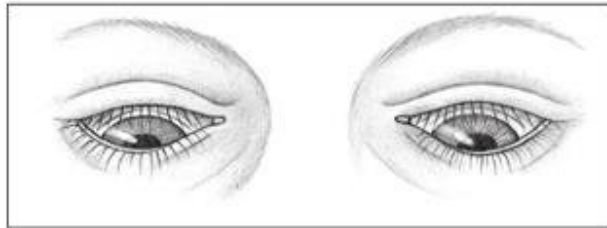
Jerk nystagmus

Convergence-retraction nystagmus refers to the irregular jerking of the eyes back into the orbit during upward gaze. It can indicate midbrain tegmental damage.

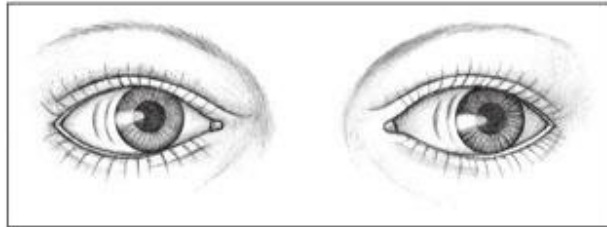


Downbeat nystagmus

refers to the irregular downward jerking of the eyes during downward gaze. It can signal lower medullary damage.

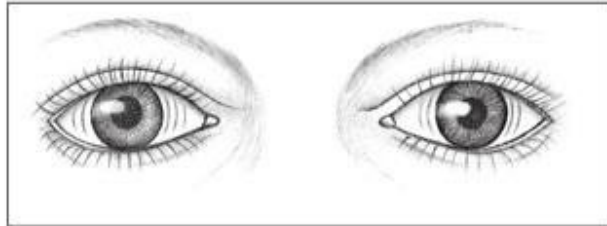


Vestibular nystagmus, the horizontal or rotary movement of the eyes, suggests vestibular disease or cochlear dysfunction.

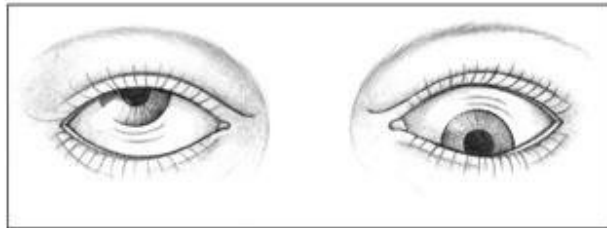


Pendular nystagmus

Horizontal, or pendular, nystagmus refers to oscillations of equal velocity around a center point. It can indicate congenital loss of visual acuity or multiple sclerosis.



Vertical, or seesaw, nystagmus is the rapid, seesaw movement of the eyes: one eye appears to rise while the other appears to fall. It suggests an optic chiasm lesion.



- types :-

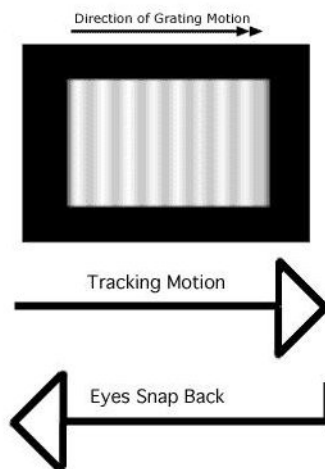
I)- Physiological nystagmus :-

a)- End point nystagmus :-

- fine jerk.
- when eyes look at extreme positions of gaze.

b)- Optokinetic nystagmus (OKN or railroad nystagmus):-

- jerk.
- induced by using optokinetic drums (a small drum with black & white stripes on its outer surface) with repeated visual stimulation.
- applied :-
 - 1)- *lesion in the occipital cortex* → homonymous hemianopia with normal OKN.
 - 2)- *lesion in optic radiation* → homonymous hemianopia with impaired OKN on the same side due to loss of pursuit movement which starts the OKN.
 - 3)- *fatigue, sedatives, anticonvulsants & excess alcohol* impair OKN.



c)- Vestibular nystagmus :-

- jerk.
- remember cold → opposite side & warm → same side in the fast phase of nystagmus.
- produced by stimulation of the semicircular canals.

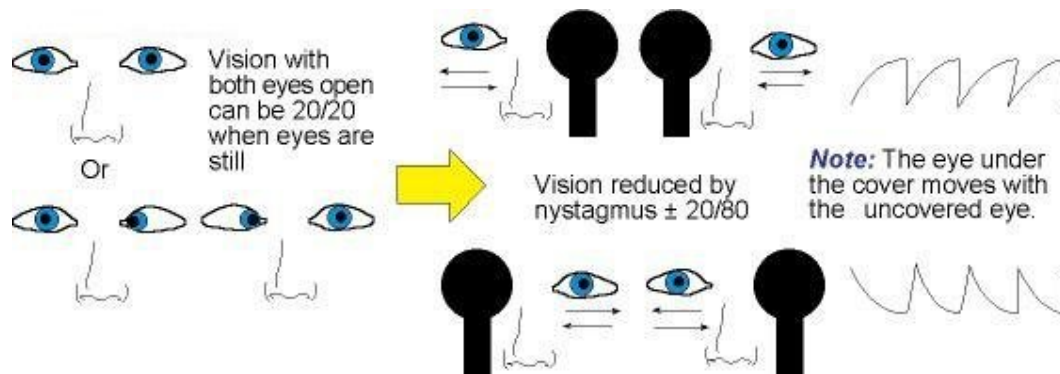
II)- Pathological nystagmus :-

a)- Congenital :-

- jerk.
- latent.

b)- Latent :-

- jerk.
- associated with infantile esotropia & dissociated vertical deviation (DVD).
- no nystagmus but when one eye is occluded or ↓ light entering it → nystagmus.



c)- Down beat :-

- jerk.
- on down gaze.
- due to lesion at site of foramen magnum.

d)- Up beat :-

- jerk.
- on up gaze.
- due to lesion in the posterior cranial fossa.

e)- See-saw :-

- pendular.
- one eye → elevation & intorsion & the other eye → depression & extorsion then the reverse occur.
- due to parasellar tumour.

f)- Sensory deprivation nystagmus :-

- pendular.

*** Classification of causes of nystagmus :-**

I)- Ocular or fixation nystagmus :-

a)- physiologically induced :-

- deviational.
- optokinetic.
- latent.

b)- spontaneous :-

- due to blindness.
- due to defective central vision.
- spasmus nutans.
- Miner's nystagmus.

II)- Vestibular nystagmus :-

- labyrinthine.
- due to vestibular nerve lesion.

III)- Nystagmus of central origin :-

- lesion in → brainstem, cerebellum or spinal cord.

IV)- Congenital idiopathic nystagmus.

V)- Voluntary & hysterical nystagmus.

10)- Binocular vision :-

- def.:- it's the ability of both eyes to see one object as a single object at the same time.
- Binocular single vision allows fusion of retinal images of the 2 eyes.

*** Advantages (characters) of binocular vision :-**

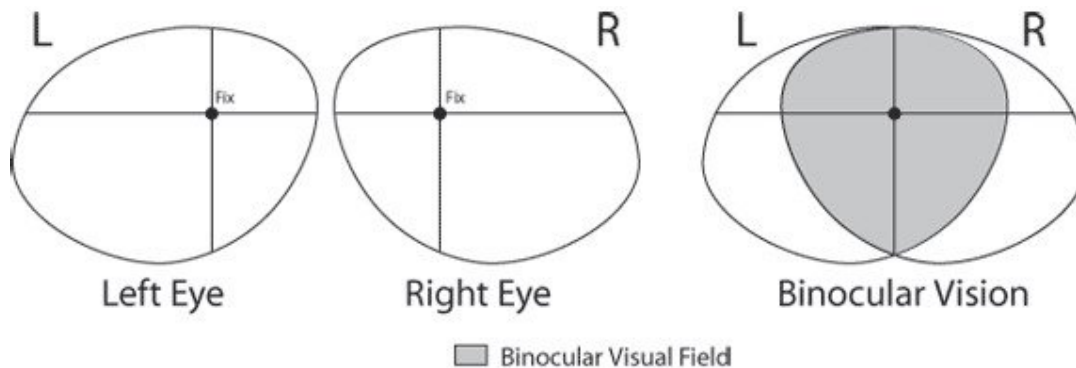
- large field of view than monocular vision.
- better VA (depth perception).

- minimal aberration (optical defects in one eye are made less obvious by the normal image of the opposite retina).
- better depth perception (stereopsis).
- visual field defects in one eye are masked.

* Requirements for binocular vision :-

I)- Considerable overlapping of both visual fields :-

- this allows objects to be located in the overlapping area of both unocular fields.
- this overlapping is called binocular field of vision.
- the binocular field is heart shaped zone extending 60° on both sides of point of fixation, 70° above & 90° below (minimal field for driving license is 20° above, 20° down & 60° on both sides).
- on each side there is a monocular crescent (temporal field) which represent the decussating nerve fibers (nasal fibers).



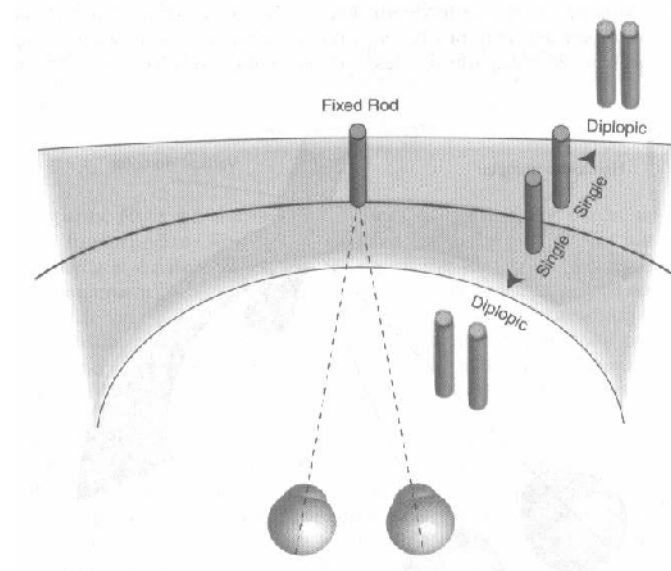
II)- Precise ocular movements & normal retinal correspondence

(RC):-

- this allows falling of both images of a single object on both corresponding retinal points (each point in one retina corresponds to a point on the other retina e.g. fovea & macula).
- the 2 corresponding points (one in each retina) have a common visual direction in the space :-

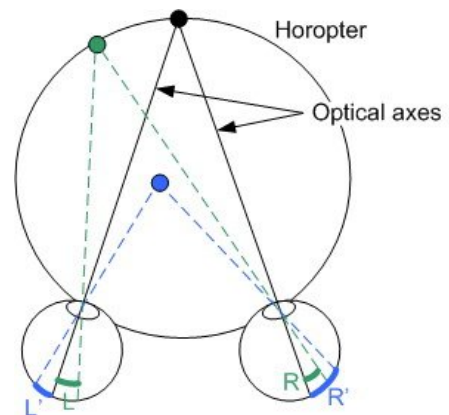
a)- Physiological diplopia :-

- when both eyes fixate to one object in space.
- the objects fall on the 2 corresponding retinal points.
- objects in front & behind the fixating object will not fall on 2 corresponding points hence seen double.
- physiological diplopia usually not felt.
- squint in children does not lead to diplopia because of abnormal retinal correspondence (ARC) i.e. retinal elements of squinting eye assumes abnormal relationship with the fovea of the straight eye.



b)- The horopter :-

- imaginary circle in space (geometrical figure ellipsoid in shape) each point of this circle stimulates 2 corresponding retinal points.
- the circle passes through the fixation points on the horopter & the nodal points of the eyes.
- the ellipsoid shape of the horopter is due to different spacing of retinal receptors in the temporal & nasal retina.
- object at 2 meters from eye allow flat horopter.

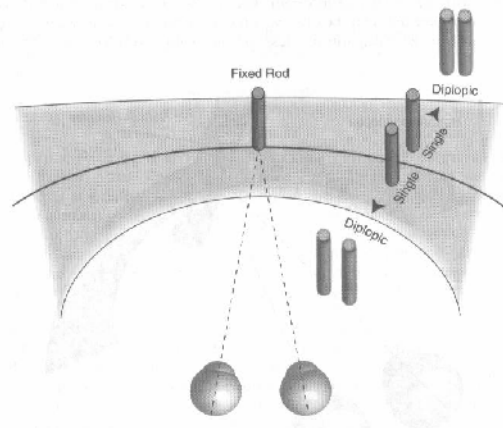


- object > 2 meters from eye allow concave horopter.
- object < 2 meters from eye allow convex horopter.

c)- Panum's area :-

- according to horopter, any object in front or behind the circle is seen double, but this is not true because of presence of Panum's area $\rightarrow$ an area in front & behind the horopter (circle), object at it is seen single binocularly.
- according to Panum's area, any point on the retina of one eye is corresponding to a small area of points on retina of the other eye & stimulation of both simultaneously will lead to fusion & binocular vision.
- so any point outside Panum's area is seen double (i.e. not fused).
- objects proximal to the fixation points project into temporal retina & form what is called bitemporal disparity.
- objects distal to the fixation points project into nasal retina to form binasal disparity.
- bitemporal disparity & binasal disparity of retinal images are the basis of binocular parallax used in differentiating the relative proximal or distal location of object point in reference to the object of regard (stereopsis).
- fusion & stereopsis both occur in response to visual stimuli arising from within Panum's area.

N.B. Panum's area corresponds to cortical units rather than retinal points.



III)- Normal visual cortex for occurrence of sensory fusion :-

- the 2 images of single object must project to the same area of the brain to be fused into one image.
- the 2 images of single object must be almost the same shape, size, colour & clarity.

* Theories of fusion :-

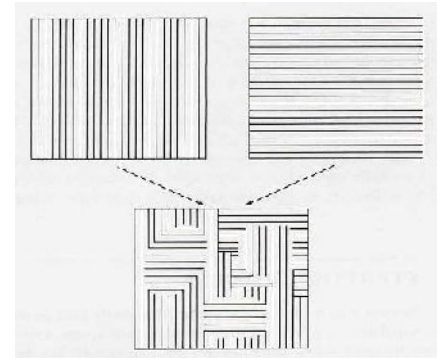
I)- Terminal effector cell theory :-

- 2 images from 2 corresponding retinal points are fused in terminal effector cells in the visual cortex area 17 (Worth & Verhoeff).
- sensation of both eyes = sum of sensation of each eye i.e. if one eye sees white & the other sees black → the sum will be grey by binocular vision.

II)- Retinal rivalry :-

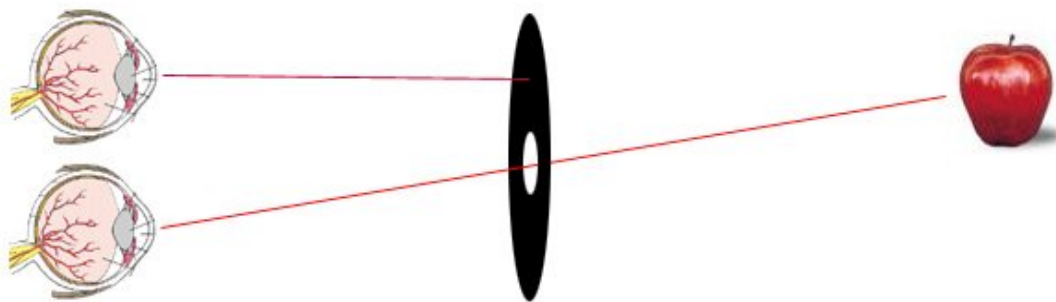
- object is seen as mosaic of the 2 images. (Verhoeff).

- ### III)- 2 independent sensations are integrated into a single perception of psychological nature (Sherrington).



* Dominant eye :-

- Rt. eye is dominant in 93% of population & image from the Rt. eye dominates in case of retinal rivalry.
- visual axis of the dominant eye passes within the center of object & visual axis of the other eye does not pass within the center of the object, but vision still single & binocular due to Panum's area.



* Fixation disparity :-

- when an object is fixed (looked at), the visual axis of the dominant eye passes in the center of the object, while the visual axis of the other eye does not pass in the center of the object but still binocular vision is obtained, this is called fixation disparity.
- it's due to Panum's area & marks the limit between physiological & pathological situations.
- occur in very small angle heterophoria less than detected by cover test.
- it measures roughly 14 min. of arc (0.5°).
- fusion becomes more difficult the more is the disparity or the difference between the 2 images.
- slight difference is necessary to get the sensation of depth.
- if the 2 images are totally different, fusion does not occur, the images are projected one over the other in the same visual direction.

* Fusion & depth perception (stereopsis):-

- when the 2 images are identical or slightly different (2nd degree fusion with the synaptophore).
- when the 2 images are totally or greatly different :-

I)- Suppression :-

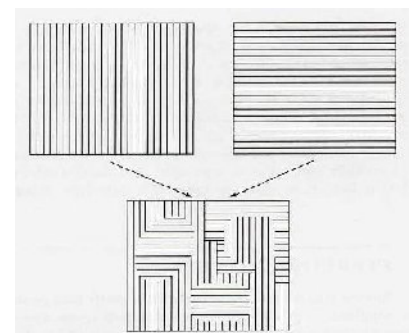
- only one image is seen to avoid diplopia.

II)- Confusion :-

- difficult fusion.
- 2 images are seen superimposed over each other in the same visual direction i.e. diplopia (1st degree simultaneous macular perception).

III)- Retinal rivalry :-

- if both images are of the same size but very different (e.g. horizontal & vertical striated lines) & fall on 2 corresponding retinal points → alternation of visual perception from one image to another.



IV)- Stereoptic luster :-

- 2 similar images of different colours are perceived as one image of particular luster not intermediate colour (e.g. white + black → not grey).

V)- Fusion of colours :-

- 2 different colours stimulate both eyes.
- the response may be rivalry (alternation of colours) or fusion (intermediate colour).
- fusion is easier when the colours are neighbours in the spectrum & their intensity is not high.

*** Development of binocular vision :-**

- at birth, the eyes are not associated with each other but act as 2 independent sense organs.
- 5 - 6 weeks after birth → the development of fixation reflex.
- by the 3rd month → foveas are formed, child learn by trial & error
- depth perception follows automatically if its factors are present.
- infant maintain fixation in all field of gaze.
- depth perception seems to be all or none phenomena.

*** Psycho-optical reflexes :-**

- these reflexes maintain eye in correct position toward the object despite movement of the object or the head :-

I)- Fixation reflex :-

- obvious at 2 - 3 month.
- types :-
 - a)- saccade → when object attracts one's attention, eye move rapidly to fix it on macula.
 - b)- pursuit → maintain fixation at macula.

II)- Conjugate fixation reflex :-

- binocular application of fixation reflex during conjugate movement.
- well established at 6 month.

III)- Vergence reflex :-

- convergence & divergence.
- it's merely the binocular application of monocular fixation reflexes.
- well established at 6 month.

IV)- Corrective fusion reflex :-

- elaboration of (II) & (III) binocularly to locate the image of same object on corresponding retinal points → object is seen as one.
- start at 1 year & well established at 5 years.
- stimulus → double vision.
- center → peristriate area.
- tested by putting Δ base-in or out in front of the eye → deviation occur to maintain fixation.

V)- Accomodative reflex.

VI)- Near reflex.

VII)- Fusional vergence :-

- concerned with adjustment of accommodation-convergence relationship in the presence of errors of refraction to maintain single binocular vision (SBV).

*** Stereopsis & Depth perception :-**

- It's a complex phenomena depending on many factors :-

I)- Geometrical factors :-

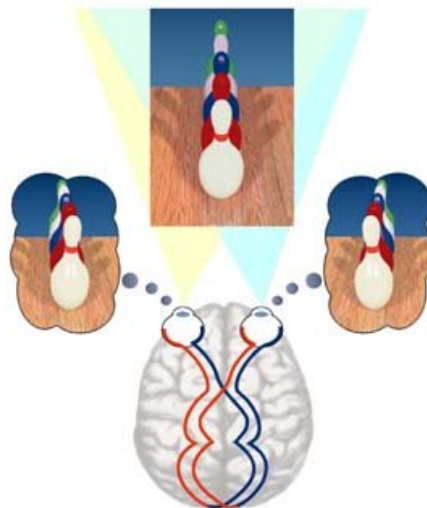
- *haziness or blue tints of objects* give impression that it is far.
- *light & shades specially in painting*, light from above makes the shadow above in a depression & below in a bulge.
- *interposition* of one object in front & another hiding parts of it.
- *horizontal parallel lines* appear to converge as these lines go away → give the impression of distance.
- *size of objects* → if the object appear smaller than its ocular size it appear far & vice versa.
- *parallactic movement* → when eyes are fixed to an object at

a moderate distance, then eyes move in one direction :-

- a)- far objects appear to move with eye movements.
- b)- near objects appear to move against eye movements.

II)- Binocular factors :-

- 2 corresponding retinal points which have common visual direction in space.
- fusion in a terminal effector cell (sensation from both eyes = sum of sensation from each eye tolerated).
- slight image disparity is the most important → image can be perceived 3 dimensional with sense of depth if these slightly different images are presented to each eye in sequence but interval must be very small i.e. less than $5'$ of an arc which is less than diameter of a single cone.



N.B. if the 2 images are very dissimilar → impossible fusion.

- *if the 2 images are exactly similar → no depth perception.*
- *tolerated disparity (due to distance between the 2 eyes) → depth perception.*

III)- Muscular factors :-

- muscular effort spent in seeing an object → convergence & accommodation.

*** Stereoscopic threshold :-**

- it is the smallest binocular disparity than can be reliably detected.
- it is assessed on statistical basis.

*** Characters of motion stereopsis :-**

- disparity → 0.1 - 10 degree.
- latency → 130 millisec.
- location → parafoveal.
- colour sensitivity → insensitive.

*** Characters of static stereopsis :-**

- disparity → 0 - 0.33 degree.
- latency → 250 millisec.
- location → foveal.
- colour sensitivity → sensitive.

*** Central single binocular vision :-**

- macular.
- of 2 components → fusion (motor part is deficient).
→ stereopsis (excellent).
- receives high attention.

*** Peripheral single binocular vision :-**

- extramacular.
- of 3 components → simultaneous perception.
→ fusion (motor part is high).
→ stereopsis (limited).
- attention is low.

* Anomalies of binocular vision :-

I)- Diplopia :-

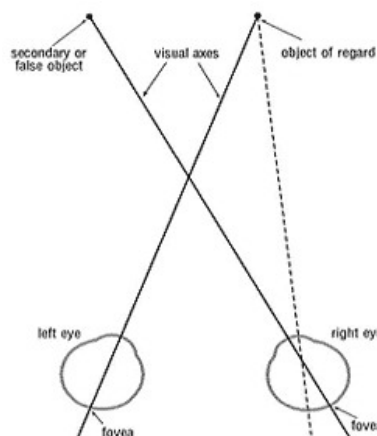
- perception of one object that projects upon 2 non corresponding retinal points.
- the result of stimulating 2 non corresponding retinal points in the 2 eyes by the same object :-

a)- Central diplopia :-

- caused by object points within the area of conscious regard projecting onto non corresponding retinal points.
- to avoid this central diplopia → suppression occurs, a facultative (only present when the eye is squinting) & absolute (no image can be visualized within).
- scotoma develops, its shape & size are different in an esotrope compared to an exotrope.

b)- Peripheral diplopia :-

- caused by object points outside area of conscious regard projecting into non corresponding retinal points.
- to avoid this peripheral diplopia, abnormal retinal correspondence occurs.
- Abnormal Retinal Correspondence (ARC):-
 - * it is a cortical adjustment in squint that permits fusion of similar images projecting onto non corresponding retinal points from object points peripheral to area of conscious regard.
 - * stereopsis is deficient & no fusional vergence amplitude.
 - * it eliminates peripheral diplopia & peripheral confusion.
 - * it is manifest only during binocular seeing.



II)- Confusion :-

- the result of stimulation of corresponding points in the 2 eyes by dissimilar images.
- consequently they are perceived as located at the same place in space.
- the object of regard is not superimposed by a different object projecting on the fovea of the squinting eye, this is due to presence of an absolute scotoma of the macula of the squinting eye, it is a physiological scotoma that prevents central confusion.

- Peripheral confusion :-

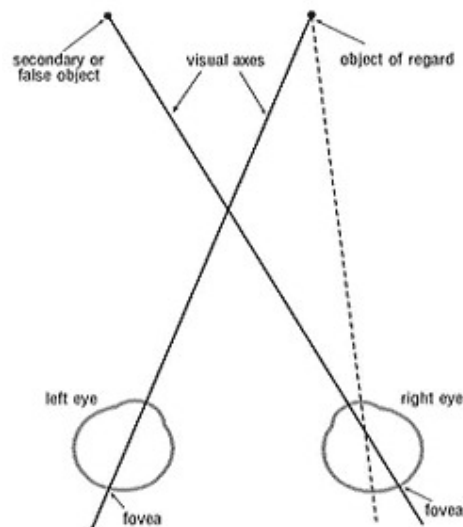
- * stimulation of corresponding retinal points (other than 2 foveas) in the 2 eyes by dissimilar images, this peripheral confusion is overcome by abnormal retinal correspondence.
- * The onset of squint in a person who has developed single binocular vision produces 3 distinct symptoms :-
 - a)- central diplopia.
 - b)- peripheral diplopia.
 - c)- peripheral confusion.
- * Cortical adaptation for these symptoms is limited to children under 10 years in the form of :-

I)- Suppression :-

- it permits the cortex to ignore visual sensation from the retina of the non-fixing eye upon which the images from the area of conscious regard are projected.
- this extramacular scotoma is pathologic (in contrast to the physiologic macular scotoma that avoids central confusion).
- this condition involves the whole retinal functions (total extinction), or may involve selectively a certain area central or peripheral (e.g. suppression scotoma in foveal area in some convergent squint), or the inhibition may be selective to a specific retinal function e.g. inhibition of resolution of colour while colour sense is intact.
- it may be monocular or alternating.
- it is absolute but facultative (later on become permanent → amblyopia).

II)- Abnormal retinal correspondence (ARC):-

- a point on the retina of the deviating eye is assigned the same visual direction as the fovea of the other eye.
- objects that fall temporal to it are interpreted as coming from the nasal field & objects nasal to it are interpreted as coming from the temporal field.



- the patient is set on the synoptophore & asked to put the line in the cage by moving the tubes of the instrument → this is the subjective angle.
- the amount of deviation measured by the doctor is the objective angle.

* Amblyopia :-

- def.:- defective vision without obvious cause or even after ttt of the cause.
- Types :-

I)- Refractive amblyopia :-

- due to anisokonia or anisometropia.

II)- Stimulus deprivation :-

- due to media opacity or ptosis.

III)- Strabismic amblyopia :-

- cortical lesion → inhibition of higher cortex (form sense) with intact lower cortical function of light perception & spatial localization (abnormal EEG).
- subcortical lesion → due to loss of activation of reticular formation anterior to chiasma in the retina itself, evidenced by :-
 - a)- relative central scotoma.
 - b)- ↓ papillary reflex.
 - c)- ↓ CFF.
 - d)- ↑ VA in low illumination.
 - e)- axis of cones are not $\perp$ to axis of RPE.

11)- Ocular Circulations :-

- uveal circulation → well developed.
 - supplies the nutritive layer.
- retinal layer → less developed.
 - can be seen by ophthalmoscope.
 - similar to cerebral circulation.

*** Uveal circulation :-**

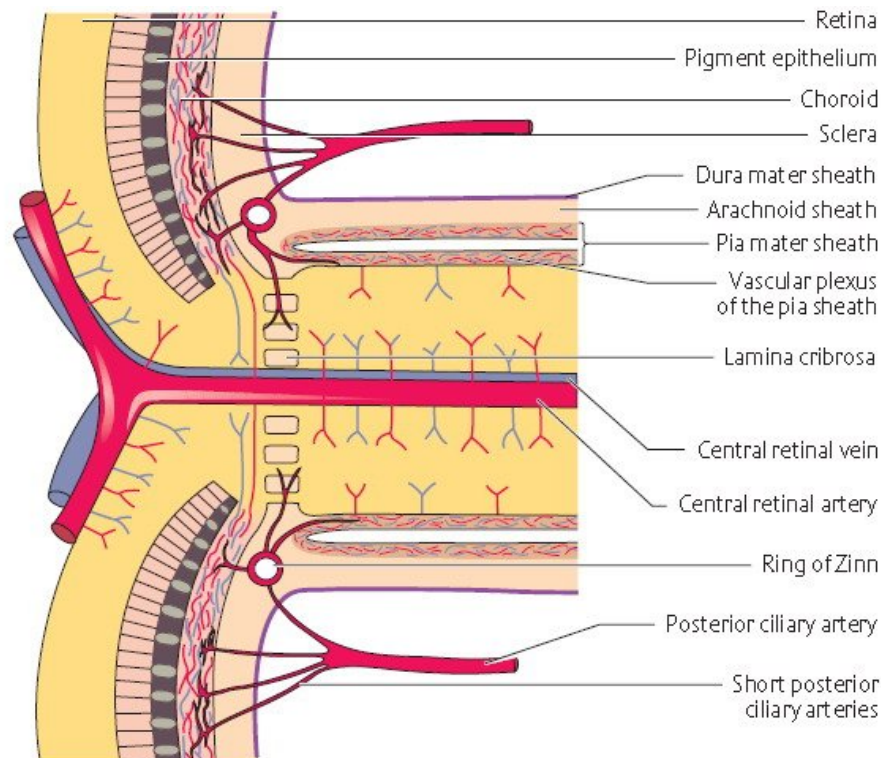
I)- Ciliary body :-

- produces aqueous humour.

II)- Iris :-

- help aqueous drainage (in & outflow).

III)- Choroidal circulation :-



a)- source :-

- posterior ciliary artery → mainly (long & short).
- recurrent arteries from major circle → partially.

b)- anastomosis of choroidal arteries is poor & liable for degeneration.

c)- 4 regions can be identified → juxtacapillary, macular, equatorial & pre-equatorial.

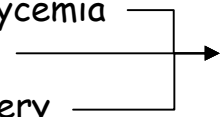
d)- Choriocapillaries :-

- junction of arteries & veins.
- large capillaries 20 μ in diameter (largest capillaries in the body).
- have large pores in their wall near the retina.
- separated from RPE by Bruch's membrane.
- easy exchange of nutrients & metabolites.

e)- Choroidal blood flow :-

- rate → 26 ml/gm tissue/min.

- value → high O_2 supply to outer layers of the retina.
 - have cooling effect against thermal damage.
 - maintain IOP.
 - carry vit.A to & from RPE.
- changes leading to disturbance of choroidal blood flow :-
 - * DM & hyperglycemia
 - * CVS diseases
 - * open eye surgery


- measurement experimentally in rabbits by :-
 - * direct catheterization of vortex veins.
 - * indirect by measuring the reflected light from the choroid after injection of Evans blue dye.

f)- Choroidal blood pressure :-

- measured by ophthalmodynamometry.
- systolic → 75 mmHg.
- diastolic → 45 mmHg.

N.B. ↑ IOP → ↓ choroidal blood flow.

g)- Neurological control :-

- only sympathetic via α -sympathetic receptors, evidences :-
 - 1)- parasympathectomy has no effect.
 - 2)- cervical sympathectomy also has no effect but sympathetic peripheral stimulation → VC → ↓ blood flow.
 - 3)- A-ch → ↑ blood flow.
 - 4)- VD drugs (e.g. A-ch, papaverine, aminophylline & theophylline)
 - retrobulbar → ↑ blood flow.
 - IV → ↓ blood flow due to ↓ BP.

h)- Control of choroidal circulation :-

- sympathetic control (most important).
- heat & light control → ↑ → ↑ flow → ↓ temperature.
- BP → ↑ BP → may ↑ choroidal bl. flow.
 - ↓ BP if not compensated by ↓ choroidal resistance → ↓ choroidal bl. flow.

- VD drugs (as before).

i)- Functions of choroidal circulation :-

- nourishment for external layers of the retina, carries vit.A to & from RPE.
- blood content is a factor in maintaining IOP, this is evidenced by :-
 - * enucleation → ↓ IOP, while obstruction of retinal circulation has no effect.
 - * rhythmic oscillation in IOP due to choroidal pulsations.
 - * ligation of posterior ciliary arteries (short & long) → ↓ IOP.
 - * ligation of the 4 vortex veins → ↑ IOP.

* Retinal circulation :-

a)- source :-

- inner 2/3 → CRA & its capillaries.
- outer 1/3 → nourishment by diffusion from choriocapillaries.

b)- Blood-Retinal barrier :-

- *inner* → between endothelial cells (zonula occludens).
- *outer* → between RPE (zonula adherens).
- consists of :-

1)- endothelium of retinal capillaries :-

- * which are joined by intercellular membrane (zonula occludens).
- * this permits only water & small sized molecules to pass readily & limit large sized molecules.
- * these are also contractile cells called pericytes which lie at the arteriole-capillary junction.
- * its contraction help to distribute the blood flow in certain areas of the retina.

2)- RPE - Bruch's membrane complex :-

- * this act as a semipermeable membrane that allows water & solutes from the choriocapillaries to the retina depending on the molecular size.

- * also RPE cells actively transport certain ions in & out of the retina by an active metabolic mechanism.
- * this mechanisms acts also by pinocytosis & active secretion to deturgesce the retina & supply essential substances for the retinal metabolism.
- this BRB is disturbed by certain traumatic & pathological conditions as DM, uveitis & intraocular inflammation resulting in :-
 - 1)- Hemorrhage :- which may be :-
 - deep from the deep capillary network.
 - superficial from the superficial capillary network.
 - 2)- Exudation of proteins & fluids :-
 - lead to edema or lipid rich exudates → circinate or star shaped exudates.
 - 3)- Leakage of serous exudates :-
 - the BRB can be studied clinically by fluoresceine angiography or vitreous fluorophotometry.

c)- Similar to cerebral circulation :-

- the same embryological origin.
- under high pressure than other tissues (IOP & intracranial tension).
- both affected by the autonomic nervous system (ANS) than peripheral circulation.
- but the retinal circulation differs from cerebral circulation in → retinal circulation is terminal with no anastmosis → more sensitive to circulatory arrest (within 5 - 8 min. → irreversible damage to the affected part).

d)- Retinal blood pressure :-

- measured in man by ophthalmodynamometry.
- systolic → 85 mmHg.
- diastolic → 65 mmHg.

e)- Principle of ophthalmodynamometry (indirect method):-

- * Principle & technique :-
 - fully dilated pupil.

- dynamometry is applied $\perp$ to the sclera while looking to the CRA by the ophthalmoscope.
- pressure is $\uparrow$ until complete collapse of the artery (systolic) then gradually $\downarrow$ until pulsations are seen (diastolic).
- if the CRA pressure is lower in one side $\rightarrow$ carotid stenosis or CRAO.
- ophthalmic artery pressure is the same in the sitting & supine positions.

* Importance :-

- compare the ophthalmic artery pressure with :-
 - 1)- *ophthalmic artery pressure of the other eye :-*
 - if the other eye is different $\rightarrow$ anisometropia because the ophthalmic artery pressure $\uparrow$ in high myopia.
 - 2)- *IOP :-*
 - if the difference is > 55 mmHg $\rightarrow$ safe optic nerve.
 - if the difference is < 35 mmHg $\rightarrow$ deterioration of optic nerve $\rightarrow$ deterioration of the visual field, this is because blood supply of the optic nerve depends on its capillaries & pressure gradient between IOP & ophthalmic artery pressure.
 - 3)- *Systemic blood pressure :-*

- _____ = $1/2 \times$ constant.

- this difference is normally not > 10 mmHg.
- if $\uparrow \rightarrow \uparrow$ cerebral vascular resistance which is not adapted to $\uparrow$ BP $\rightarrow \downarrow$ cerebral blood flow.

N.B. venous pressure is 2 mmHg $>$ IOP $\rightarrow$ prevent collapse of the veins.

- *venous pressure depends on $\rightarrow$ IOP.*
 - $\rightarrow$ CRA pressure.
 - $\rightarrow$ intracranial pressure.
- *disappearance of retinal venous pulsations $\rightarrow$ early sign of $\uparrow$ ICT.*

f)- Retinal vessels pulsations :-

1)- Arterial pulsations :-

* expansile pulsations :-

- it is due to transmission of cardiac contractions when IOP $>$ diastolic pressure or when there is a high pulse pressure.

- the arterial channel widens & collapse with systolic & diastolic contraction.

* *serpentine pulsations* :-

- difficult to be observed.
- pressure of blood on the convexity of the arteries.
- it is favored by tortuous or dilated arteries, large pulse pressure (in aortic incompetence or anemia) & minimal blood viscosity.

2)- Venous pulsations :-

- absence of venous pulsations → early sign of ↑ ICT.
- ↑ ICT → pressure on the veins → ↓ blood flow → ↓ pressure inside the veins until it becomes < IOP → venous collapse.
- frequently seen in young age.
- depends on the relation between the IOP & venous pressure.
- the venous pressure during diastole should be > IOP so as to be able to see the venous pulsations.

g)- Capillary permeability depends on :-

1)- Passive transport :-

- of low MW substances e.g. H_2O , glucose & ions but prevent passage of large molecules → maintenance of retinal transparency.
- depends on :-
 - * hydrostatic pressure which push substances out (more at the arteriolar end).
 - * osmotic pressure attract substances in & more at the venular end.
 - * MW of substances.
 - * solubility of substances in the cell membrane.
- the net result is extravasation out of the capillaries while at the venous end attraction inside the capillaries occur.

2)- Active transport :-

- of substances against concentration gradient.
- this needs energy (supplied by ATP) & substances (carried out by enzymes).

*N.B. Capillary permeability is $\uparrow$ by $\rightarrow$ capillary dilatation.
 $\rightarrow \uparrow$ capillary pressure.
 $\rightarrow \downarrow O_2$.
 $\rightarrow$ thermal & mechanical injuries $\rightarrow$ PG release.*

h)- Control of retinal circulation :-

- not under control of ANS so retinal circulation is kept by auto regulation which is sensitive to :-

1)- $\downarrow O_2$:-

- acute $\rightarrow \downarrow$ perfusion pressure $\rightarrow$ acute $\downarrow$ in O_2 tension (as in acute $\uparrow$ in IOP).
- chronic $\rightarrow \downarrow$ perfusion pressure $\rightarrow$ chronic $\downarrow$ in O_2 tension $\rightarrow$ neovascularization.

2)- $\uparrow O_2$:-

- lead to VC of BVs specially in prematures ($\uparrow O_2 \rightarrow$ VC, while withdrawal of $O_2 \rightarrow$ retinopathy of prematurity).

3)- $\uparrow CO_2$:-

- VD of retinal BVs.

4)- Metabolites :-

- produced by retinal vascular occlusion $\rightarrow$ VD after initial occlusion.

5)- Drugs :-

- VD $\rightarrow$ no effect.
- drugs $\uparrow$ COP (e.g. digitalis) $\rightarrow \uparrow$ retinal blood flow.

*** Factors affecting ocular circulations :-**

I)- Vascular factors :-

- vascular resistance $\rightarrow$ by venous congestion e.g. due to $\uparrow$ IOP $\rightarrow \downarrow$ flow.
- perfusion pressure = pressure of the artery entering the eye - pressure of the vein leaving the eye.
- blood viscosity $\rightarrow \uparrow$ viscosity $\rightarrow \downarrow$ flow.

II)- Neurological factors :-**a)- sympathetic (VC) nerve supply :-**

- sympathetic nerve supply to the uveal BVs → ↓ uveal blood flow.
- acute stress → sympathetic stimulation → VC → ↓ uveal blood flow via α-receptors in the BVs wall.

N.B. no sympathetic supply to the retina as the sympathetic supply of the CRA stop at the lamina cribrosa.

b)- axon or antidromal effect (axon reflex):-

- stimulation of the sensory nerves of the eye e.g. by corneal FB lead to → PG release → miosis.
 - ↑ permeability.
 - ↑ IOP.
 - localized VD.

N.B. the VD resist the VC effect of VC drugs after surgery.

III)- Chemical factors :-

- medullary & hypothalamic centers are controlled by O_2 & CO_2 blood levels → ↑ O_2 & ↓ CO_2 → VC → ↓ blood flow.
 - ↓ O_2 & ↑ CO_2 → VD → ↑ blood flow.

IV)- Drugs :-

- vasodilators.

V)- State of the BVs wall :-

- retinal capillaries have characteristic effect :-
 - * thick endothelium without fenestrations.
 - * thick BM & it has a direct contact with the glial tissue.
 - * they are not affected by histamine.

VI)- Altitudinal forces :-

- +ve gravity forces → blackout phenomena.
- -ve gravity forces → red out phenomena.

* Perfusion pressure :-

- def.:- difference in the pressure of the arteries entering & veins leaving the eye (almost equal to IOP).

$$\text{Perfusion pressure} = P_{\text{arterial}} - P_{\text{venous}}$$

Blood flow = _____

* Factors ↓ perfusion pressure in uvea & retina :-

a)- ↓ arterial blood pressure :-

- this explain blackout, because pressure in the Lt. ventricle is not high enough to overcome the effect gravity on the blood column from heart to the eye → ↓ blood flow → ↓ perfusion pressure → ocular ischemia.
- now believed to be due to cortical ischemia as the retinal functions are normal.

b)- ↑ IOP :-

- lead to ↑ intraocular venous pressure → ↑ vascular resistance → ↓ perfusion pressure → ↓ blood flow.

* What happens when perfusion pressure is ↓ :-

- ↓ perfusion pressure → VD of retinal BVs that maintain a steady level of blood flow (auto regulation).

* Mechanisms of auto regulation :-

a)- Myogenic :-

- through ↑ activity of pacemaker cells in the arteriolar wall → ↓ vascular tone → ↓ resistance.

b)- Metabolic :-

- through local accumulation of VD metabolites e.g. CO_2 → VD → ↓ vascular resistance.

*** Aviation :-**

I)- Gravitational effect :-

a)- effect of acceleration (rapid ascending against gravity):-

- will ↓ blood flow to the head → ↓ retinal supply → ↓ O_2 to the retina & brain ischemia :-
 - * *grey out* :- ↓ vision due to rods degeneration as they are sensitive to ischemia > cones.
 - * *blackout* :- loss of vision as the cones are affected.
 - * convulsions up to loss of consciousness.

N.B. ↓ blood → rods → grey out.

→ *cones* → *blackout*.

→ *brain* → *convulsions & loss of consciousness.*

b)- effect of deceleration (rapid descending with gravity):-

- will ↑ the blood flow to the head :-
 - * ↑ retinal BVs congestion → red out → red vision (no loss of vision).
 - * flushing of the face & sense of confusion → patient feels that his head is about to rupture.

II)- Altitudinal effect :-

a)- Acute symptoms :-

- cerebral anoxia > 5 min. → irritation.
 < 5 min. → paralysis.
- ↓ all retinal functions due to disturbed conduction at synapses &
 ↓ sensitivity of neural elements.
- ↓ night vision because rods are more sensitive to ischemia > cones.
- ↓ accommodation.
- ↓ light perception.
- contraction of the peripheral field 1st as the rods are more
 susceptible to anoxia.
- muscular imbalance.
- ↓ CFF.
- ERG → absent b-wave.

b)- Chronic symptoms :-

- due to repeated exposure to high attitudes > 12000 feet.
- usually occurs after 3 weeks.

1)- ↑ *muscular imbalance* :-

- ↓ accuracy of saccadic eye movements.
- unsteady fixation.
- divergence of axes during fixation pause & convergence of axes during saccadic movements.

2)- ↑ *peripheral field contraction* :-

- occasional central field contraction.

تمت بحمد الله
